Trauma, Critical Care and Surgical Emergencies

A Case and Evidence-Based Textbook

Edited by

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Preface

This book focuses on trauma, surgical critical care, and surgical emergencies. Each of these surgical subspecialties involves critically ill patients, who by virtue of their diseases require immediate attention by an expert surgeon as well as allocation of specific resources. Although trauma, surgical critical care, and surgical emergencies inherently complement each other, they were integrated into one surgical specialty, termed Acute Care Surgery, only recently following several evolutionary processes. First, trauma surgery became much less operative with the advent of computed tomography, interventional radiology, intravascular stenting, and improved resuscitation modalities. In addition, the incidence of penetrating trauma, the most common mechanism of injury requiring operative intervention, has sharply declined due to improved policing and more efficient drug control. Lastly, the philosophy of "total commitment" of the trauma surgeon, advocated by the American College of Surgeons Committee on Trauma, led to diminished involvement of other specialists in the management of trauma patients. As a result, trauma experts got more involved in the non-operative management of patients with extra-torso trauma. These practice trends shrunk the scope of trauma surgery and forced trauma surgeons, who only a decade ago used to be busy operating on almost all body areas, to look for other options to maintain their operative skills. The most natural option has been caring for surgical emergency patients, who like trauma victims, present with acute conditions requiring attention by an immediately available surgeon. The fusion of trauma surgery and emergency general surgery was facilitated by a second evolutionary process. Due to deteriorating reimbursements and changes in lifestyles, many general surgeons became more reluctant to take general surgery calls, which interfere with the more profitable elective operative schedule and which negatively impact quality of life. Third, surgical critical care developed into a highly specific, viable field, which attracted many trauma surgeons wishing to provide an entire spectrum of care to their patients. Consequently, a large number of institutions combined their trauma and surgical critical care fellowships and many hospitals are now requiring newly recruited attending to have both trauma and critical care qualifications.

Since an increasing number of trauma surgeons across the country combine trauma care with both surgical critical care and surgical emergencies, and as most surgical societies aggressively promote this concept, we believe that this book has a clear niche in the surgical literature. This textbook aims to provide a comprehensive and contemporary discussion of the three arms of acute care surgery. By providing a single resource where surgeons can find answers to most questions related to this subspecialty, we hope to improve the care of trauma, surgical critical care, and surgical emergency patients. We also hope that this book will assist trauma, critical care, and general surgeons in addressing the formidable challenges of managing acutely ill surgical patients. Finally, we believe that this textbook will be useful to surgical fellows, residents and medical students, as they develop into mature surgeons.

This textbook includes evidence-based analysis by leading experts in the field of cases representing fundamental clinical issues and controversies. Each of the 65 chapters starts with a case presentation, which is being followed as the chapter evolves. The authors review key points in an evidence-based fashion and correlate them to the presented case. Unless stated otherwise, the authors used the GRADE evidence classification system established the American College of Chest Physicians (see Appendix 1). This case- and evidence-based approach makes our book livelier and easier to read than the traditional textbook. It has three sections: Trauma Surgery edited by Dr. Reuven Rabinovici, Surgical Critical Care edited by Dr. Heidi Frankel, and Surgical Emergencies edited by Dr. Orlando Kirton.

We were proud to invite Dr. Erwin Hirsh and Dr. John Pryor to contribute to this book. Unfortunately, Dr. Hirshs unexpected death prevented him from completing his chapter on blunt splenic injury. We are forever grateful to Dr. Pryor, who died while on active duty in Iraq, for his most comprehensive chapter on acute cholecystitis. We dedicate our book to the memory of these two outstanding surgeons.

Finally, we would like to acknowledge the support we got from our families, mentors, and colleagues. We recognize that without their assistance this book would have not been possible.

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Evidence-based Medicine in Emergency Surgical Care
Timothy C Fabian

INTRODUCTION

I became involved with evidence-based medicine about a decade ago by way of activities associated with the Eastern Association for the Surgery of Trauma (EAST).(1) At that time, the organization became interested in developing practice management guidelines for trauma care. This was a somewhat novel and controversial concept at that time. In retrospect, it seems rather ironic to consider using evidence-based methodology to drive standards of medical care as controversial. The paradox can be underscored through a little vignette from that time.

I was traveling on an airplane for a meeting dealing with evidence-based medicine. While reviewing my computer presentation on the plane, the lady sitting next to me apologized for interrupting, but was intrigued by my preoccupation with the computer screen. She asked what I was working on and I told her, "It's a fairly new concept involving evidence-based care in medicine. We have begun to base management decisions on objective evidence accumulated through various clinical research studies." Somewhat astonished, she asked, "What has medical care been based on up to now?" That lady's startled response instantly drove home to me the rather rudimentary manner in which clinical care has developed over time.

In this chapter, some of the nomenclature and definitions required for an understanding of the applications of evidence-based medicine (EBM) will be discussed. Arguments for and against EBM will be considered. Several methodologies related to the development of evidence-based approaches to care will be described. The chapter will conclude with considerations for the future development of evidence-based medical processes, and the important consideration of how they can be disseminated and applied.

NOMENCLATURE OF EVIDENCE-BASED MEDICAL PRACTICE

The definition of evidence-based medicine seems to originate from McMaster University in Hamilton, Ontario in the early 1990s: "Evidence-Based Medicine—The conscientious and judicious use of current best evidence from clinical care research in the management of individual patients."(2) Over the last 15 years, three general types of evidence-based tools have been applied in clinical practice. These include practice management guidelines, clinical pathways, and protocols. *Management Guidelines* describe approaches for prevention, diagnosis, evaluation, and/or management of actual or potential disease processes. *Clinical Pathways* are care plans established in a time-dependent fashion for disease management. Clinical pathways have become widely applied in inpatient care especially by the nursing profession. Pathways lend themselves well to disease diagnosis and management for those problems which are relatively homogenous in presentation and which lend themselves

to discrete sequencing of care. Examples would include management of pneumonia, acute myocardial infarction, and the timed implementation of various components of the care of patients undergoing elective operative procedures such as coronary bypass grafting, or gastrointestinal resection. They are less easily applied to trauma patients because of the heterogeneity of patients, especially relative to multiplicity and combinations of injury types as well as to variations in patient ages and co-morbidities. For diagnosis and management of specific organ injuries management guidelines tend to be more practicable. **Protocols** are formulas used for guideline application and these include algorithms and decision analyses trees. They can be considered diagrammatic illustrations of management guidelines. They usually take an "if—then" format. Since practice management guidelines are the most workable evidence-based tools for use in trauma care, this chapter will deal primarily with guideline utilization and the processes used for their development.

EVOLUTION OF CLINICAL DECISION MAKING

Clinical management "guidelines" in the broad sense could be considered to be steeped in the days of medical apprenticeship. Apprenticeship, a system largely based upon individual experience, was the standard method of physician learning up to the early part of the 20th Century. A substantial part of medical care developed through local/regional customs, hearsay, and dogma—a phenomenon that continues today. Textbooks gradually became an important adjunct for clinical care, but were not widely available to trainees until well into the 20th Century. Textbooks continue to provide an important background of evidence for medical care because of the inefficiencies associated with the traditional publishing processes. The data contained in textbooks is usually several years behind times relative to new discoveries which have occurred in the publication interval—a disturbing thought relative to this enterprise!

Medical journals have become the leading source for providing objective data for rational clinical practice. But, given the current structure of medical practice, a significant drawback to relying only on the raw information generated from the medical journal literature for decision-making, is the fact that the sheer number of journals overwhelms even the most dedicated practitioner. When speaking on current information management, Al Gore noted: "… resembling the worst aspects of our agricultural policy, which left grain rotting in thousands of storage bins while people were starving." Indeed, that is the sad status of a lot of good clinical research. There are significant quantities of research in the medical literature but it is next to impossible for the average person to digest much more than a small fragment. There simply is not enough time to keep up with all data generated unless one is involved only in an extremely isolated and focused area.

In order for information to be clinically useful it must be readily accessible.

(Relevance) (Validity)

Usefulness of Medical Information = Work

Usefulness is directly proportional to relevance and validity and indirectly proportional to the effort required to obtain the information. Management guidelines can improve the usefulness of the extant medical literature by classifying and synthesizing the clinical research and minimize the effort when professional organizations develop organized evidence-based evaluations. Additionally, the clinical research required for decision-making processes in most areas of practice today is completely inadequate. Those problems have led to formalized processes for development of the evidence-based management tools.

Systematic approaches for data analysis have been developed in recent decades. One of the earliest and most extensively applied has been the Delphi method, which is a structured approach to developing consensus using a panel of independent experts.(3) The Delphi method has been widely utilized by the National Institutes of Health to make recommendations through consensus panels on a myriad of healthcare issues addressing disease management and prevention. But, consensus statements are now giving way to more data driven approaches for management recommendations.

RATIONALE FOR EVIDENCE-BASED MEDICAL PRACTICE

Healthcare has been gradually gravitating toward evidence-based practice over the last decade. There are multiple forces that have led to adoption of these principles. Those forces include utilization management in an attempt to maximize quality and efficiency in the delivery of healthcare. "Score cards" based on process evaluation of the use of evidence based patient management are being employed. These auditing processes are increasingly being applied for profiling of hospitals as well as credentialing of individual physicians. Many institutions rely on them for risk management tracking. Those score cards are also used in managed care contract negotiations. Unfortunately, hospital systems are using them today for marketing activities—perhaps a healthcare example of the rich getting richer, and the poor getting poorer. I hope their reporting is honest and accurate.

The primary rationale for management guidelines should be to aid in provision of high quality, efficient patient care. It has been suggested, though not documented, that in addition to maximizing quality, management guidelines are also cost effective. Financial value should be attained by helping establishing best practices and from the prevention of complications. This approach leads to efficiencies gained through minimization of disparate approaches to the same problem. While management guidelines should be directed by physicians involved in the area of care for which the guideline was developed, multispecialty collaboration with nursing, pharmacy, and other departments provides for optimal development and compliance.

If the medical profession fails to establish evidence-based guidelines, then other organizations including industry and government will fill the vacuum. Milliman and Robertson, Inc. produced Healthcare Management Guidelines ™ in seven volumes (www.careguidelines.com) (4): Inpatient and Surgical Care, Return to Work Planning, Ambulatory Surgery Guidelines, Homecare and Case Management, Primary and Pharmaceutical Care, Case Management: Recovery Facility Care, Worker's Compensation. Their development processes are proprietary and not transparent.

The Centers for Medicare and Medicaid Services (CMS) have begun utilizing the Surgical Care Improvement Project (SCIP) (5) measures to evaluate hospital performance, and ultimately those measures will be applied for individual physician tracking and profiling. Indeed, pay for performance ("p4p") initiatives are being designed with these evidence-based principles as a metric for hospital and physician performance. The initial SCIP measures address appropriate prophylactic antibiotic administration, venous thromboembolism prophylaxis, stress ulcer prophylaxis, mechanical ventilator weaning protocols and nosocomial pneumonia prevention measures. CMS is also in the process of discontinuing payment for in-hospital complications that they insinuate can be reduced by application of evidence-based practice patterns, some of which are included in the SCIP measures. The complications CMS plan on stop reimbursing include central line infections, urinary tract infection associated with bladder catheterization, and nosocomial pneumonia. CMS may expand non-reimbursement policies via the pay for performance program in the future. But, it should be noted that the *process* of utilization of evidence-based practices are being measured rather than *outcomes*. The application of evidence-based practice and management guidelines should reduce, but not eliminate, many of these complications. Other forces promoting the use of practice guidelines include implications that they will decrease diagnostic testing, reduce practice pattern variation, and that those measures will ultimately improve quality of care and patient outcomes. Only time will tell if all of these advantages will be realized.

All of the interest in the application of management guidelines has not been positive. There have been concerns that the use of evidence-based guidelines could have deleterious effects on medicolegal issues. Most of the apprehension centers around the concept of "standard of care," which is generally defined as the degree of knowledge, skill, and care that a competent practitioner would have exercised under circumstances similar to those faced by a physician accused of malpractice. Arguments against evidence-based guidelines are that the standard of care might be defined more rigidly than is justified. It must be recognized that management guidelines are, in fact, *guidelines*. They are intended for application to populations of patients and not necessarily to each individual. Indeed, it can be argued that there is insufficient data in most areas to establish true "standards". Nonetheless, standards of care are established in the courtroom from many sources. Traditionally, textbooks and medical journals have been applied in the courts for defining standards of care in medical malpractice. Expert witness testimony is also heavily relied upon. As alluded to, the utilization of textbook standards becomes problematic because from the time of authorship to that of publication, textbook development is generally 2–4 years. Clinical research may have occurred in the interval, which essentially puts

some of the information in textbooks out of date by the time the books are published.

Because of these issues, practice management guidelines have been promoted for use related to liability. It has been suggested that they can have both inculpatory and exculpatory purposes. A report on 259 medicolegal claims addressed the use of guidelines.(6) Seventeen of the 259 were guidelines cases and the remaining 242 did not involve guidelines. Of the 17 cases, four were used for exculpatory purposes and 12 used for inculpatory purposes. Of the 12 inculpatory applications, there was one jury verdict for the defendant, eight settled with payment to the plaintiff, one was closed with no payment, and at the time of the publication of the article, two remained open. Of the four cases where evidence-based guidelines were used for exculpatory purposes, one had a jury verdict for the plaintiff, one settled with payment to the plaintiff, and two remained open at the time of publication. Overall, current evidence seems to be neither particularly strong for, nor against, the use of guidelines relative to medicolegal risk for defendants.

MANAGEMENT GUIDELINE DEVELOPMENT PROCESSES

A structured process for evaluation of clinical research has become the key tool for development of management guidelines. This process will be referred to as the evidence-based outcome evaluation (EBOE). Several organizations have developed management guidelines using this fundamental approach. It is a defined structure for evaluation of clinical research that results in recommendations based on the quality and strength of the available evidence. The EBOE becomes the engine driving management guidelines. It is a major undertaking for an association to adopt the methodologies involved with production of EBOEs and the subsequent development of management guidelines. Resources including time, organizational energy, and money are dedicated not only to guideline development, but also to the critically important issue of keeping the management guidelines up to date and accurate. Ongoing peer reviews of existing management guidelines are required to keep them current relative to the generation of new information from clinical research which has emerged since the guideline was established. Importantly, major goals of the EBOE are evaluation for bias in the literature, and to minimize the impact of bias on management recommendations. There are several types of bias that need to be screened. *Allocation or selection bias* occurs with enrollment of patients into a randomized controlled trial (RCT). Appropriate randomization processes can minimize selection bias, with double-blinding being the optimal randomization method for controlled trials. *Investigator bias* may occur at many steps in the clinical trial beginning with allocation of the research subject into the trial arm. Furthermore, in a blinded trial, allocation blinding should not be broken until the analysis is completed. Some RCTs become contaminated due to early violation of this principle. Investigator bias can be difficult to ascertain. *Statistical bias* can occur from both alpha and beta errors. Alpha error, also referred to as type I error, is made in testing an hypothesis when it is concluded that a result is positive when it really is not. Alpha error is often referred to as a false positive. Alpha error occurs when there is no difference between the alternatives in a randomized trial although the p-value is deemed

significant, i.e. with a p-value of $p < .05$; this is when the one in 20 exceptions occurs. Beta error, also referred to as type II error, is made in testing a hypothesis when it is concluded that the result is negative when it really is positive. Beta error is often referred to as a false negative. A beta error occurs in trials where no significant differences are found, but in fact the trial was too small, and not powered to detect the truly significant differences. This is a common finding in single institution RCTs. It is an important consideration for many clinical questions and which underscores the importance of performing multi-institutional trials in order to have a large enough population to test management uncertainties. *Publication bias* occurs when no differences are found in a trial. Journals are reluctant to publish "negative results." Negative trials can be quite helpful in developing management recommendations as well as framing questions for future research. One attempt to alleviate this problem is a registry for *all* RCTs that has been established by the Cochrane Collaboration.(7)

There are two general approaches to development of the EBOE—Statistical Analysis and Critical Analysis. *Statistical Analysis* requires RCTs and if there are enough robust trials available, recommendations can be made solely on the basis of the RCTs results. Unfortunately, there are very few areas in clinical medicine that have a satisfactory number and/or quality of RCTs which alone provide an adequate amount of information to drive decision-making. Hence, meta-analytic tools have been used as another form of statistical analysis.(8)

Meta-analysis involves evaluation of multiple small, randomized, controlled trials to address the clinical question. If several trials are available, meta-analytic techniques may provide a high degree of confidence of effect impact. However, there are several shortcomings of meta-analysis for decision-making. Many RCTs are single institutional trials that contain relatively small numbers of patients. They usually do not include exactly the same types of patients, data sets are rarely uniform, and while the outcomes evaluated may be similar, they are often not identical. While meta-analyses can provide focused, strong recommendations for management guidelines, more often vagaries amongst the included trials do not lend themselves to firm recommendations for management.

Critical Analysis is used to formulate EBOEs by strictly defined data collection and classification methodology of the medical literature on particular management questions, and to apply assessments based on evaluation of the accumulated literature review in order to make recommendations and develop patient management guidelines. Several organizations have used the critical analytic processes to develop management guidelines. While the processes used by the various organizations to develop guidelines are not identical, they are similar.

The Agency for Healthcare Quality and Research (AHQR) has provided significant guidance in the whole arena of evidence-based medicine. An important consideration for guideline development is the starting point of topic selection. AHRQ suggests selecting areas of high incidence or prevalence and areas associated with high cost. It is also advisable to select areas where there is controversy or equipoise relative to diagnosis or management. Realms for study in which there is potential to reduce significant variations in practice are fertile grounds for guideline

development. When several approaches to patient care are being applied, common sense dictates that all cannot be optimal, and direction is desirable. Wennberg, and colleagues have produced a large amount of data documenting wide variations in the performance of multiple surgical procedures. A 20-fold difference in carotid endarterectomy in 16 large communities in four states has been reported.(9) The rate of tonsillectomy in Vermont has been demonstrated to vary 8–70% among regions.(10) Hysterectomy was reported in Maine to vary between 20 and 70%.(10) Chassen has likewise demonstrated a variation of over 300% for over half of the procedures for Medicare in 13 metropolitan areas in the United States.(11)

For topic selection it is also advisable to select domains in which there is a reasonable availability of scientific data in order to make sound decisions. Ideally, the area of study should have the potential for reasonably rapid implementation in order to justify the expense and energy put into the process.

The following steps are generally followed by professional organizations which embark on management guideline development.(12)

1. Formulation of clear definition, scope, and impact of a disease over time using a multidisciplinary team.
2. Generation of specific clinical and economic questions and search the literature.
3. Critically appraise and synthesize the evidence.
4. Evaluate the benefits, risks, and costs.
5. Develop evidence-based guidelines, pathways, and protocols.
6. Implement the guidelines, pathways, and protocols.

The entire process of management guideline development centers around recruiting *study groups* of individuals with the appropriate expertise and energy required for the somewhat intricate and arduous processes of developing the EBOE (Figure 1). Panels and panel chairpersons should be selected for each topic selected. Members of the panel often require varied physician specialists, nurses, pharmacists, methodologists, health economists, and other disciplines. The importance of multi-disciplinary participation for both expertise and acceptance cannot be overemphasized.

Step 3, which involves literature search and data classification, is the foundation for reliable, high quality guidelines. Expertise provided by formally trained *methodologists* adds greatly to the quality of guideline development. They have defined approaches to search out even unpublished trials which may provide important direction for completion of the resulting EBOE. Both MEDLINE (Pub Med) and EMBASE (European medical literature data base) should be routinely used. The references from articles identified by the primary literature searches should also be queried. Following literature retrieval, the quality of the individual studies is assessed. Table 1 Illustrates an assessment classification system which was developed by the Canadian and U.S. Preventative Task Force.

Similar classifications are used by all organizations involved with guideline development. The final step is to make recommendations based on the classified data.

Table 2 Illustrates the system of *confidence levels* used by the Eastern Association for the surgery of trauma for their Trauma Guidelines Project.(12)
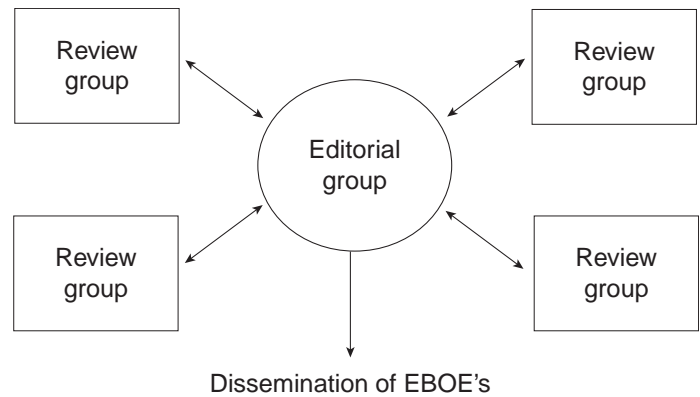
Figure 1 Schematic overview of the process for evidence based outcome evaluation (EBOE) development.

Table 1 Grading system developed by the Canadian and U.S. Preventative Task Force.

Class I:	Prospective randomized, controlled trials—may be weak
Class II:	Prospective, nonrandomized, retrospective analyses, clear controls
Class III:	Retrospective, observational, expert opinion

Table 2 Grading system used by EAST.

Level I:	Justified based on scientific evidence—usually Class I data
Level II:	Reasonably justified by scientific evidence and strongly supported by expert opinion—usually Class I or II data*
Level III:	Supported by available data, but scientific evidence is lacking*

Levels II and III are useful for guiding further research

In this book, the authors use a grading system established by the American College of Chest Physicians (Table 3).(13) This system, which is a modification of the grading scheme formulated by the international GRADE group, classifies recommendations as strong (grade 1) or weak (grade 2), according to the balance among benefits, risks, burdens, and possibly cost, and the degree of confidence in estimates of benefits, risks, and burdens. The system classifies quality of evidence as high (grade A), moderate (grade B), or low (grade C) according to factors that include the study design, the consistency of the results, and the directness of the evidence. Again, this is a system similar to those used by other organizations for guideline formulation.

Several organizations have developed guidelines for trauma patient management based on these principles of *critical analysis*. The Brain Trauma Foundation has used this approach in developing multiple guidelines related to management of traumatic brain injury (www.braintrauma.org).(14) Those guidelines have been published in three treatises which address prehospital management of severe traumatic brain injury, management of severe traumatic brain injury, and the surgical management of traumatic brain injury. The Society of Critical Care Medicine has developed several guidelines pertaining to critical care management including sepsis, sedation, venous thromboembolism, and ventilatory management.(15)

Table 3 Grading system of the ACCP Used in This Book.

Grade of Recommendation/Description	Benefit vs. Risk and Burdens	Methodological Quality of Supporting Evidence	Implications
1A/strong recommendation, high-quality evidence	Benefits clearly outweigh risk and burdens, or vice versa	RCTs without important limitations or overwhelming evidence from observational studies	Strong recommendations, can apply to most patients in most circumstances without reservation
1B/strong recommendation, moderate quality evidence	Benefits clearly outweigh risk and burdens, or vice versa	RCTs with important limitations (inconsistent results, methodological flaws, indirect or imprecise) or exceptionally strong evidence from observational studies.	Strong recommendation, can apply to most patients in most circumstances without reservation
1C/strong recommendation, low-quality, or very low-quality evidence	Benefits clearly outweigh risk and burdens, or vice versa	Observational studies or case series	Strong recommendation but may change when higher quality evidence becomes available.
2A/weak recommendation, high-quality evidence	Benefits closely balanced with risks and burden	RCTs without important limitations or overwhelming evidence from observational studies.	Weak recommendation, best action may differ depending on circumstances or patients' or societal values.
2B/weak recommendation, moderate-quality evidence	Benefits closely balanced with risks and burden	RCTs with important limitations (inconsistent results, methodological flaws, indirect or imprecise) or exceptionally strong evidence from observational studies	Weak recommendation, best action may differ depending on circumstances or patients' or societal values.
2C/weak recommendation, low-quality or very low-quality evidence	Uncertainty in the estimates of benefits, risks and burdens; benefits, risk and burden may be closely balanced	Observational studies or case series	Very weak recommendations: other alternatives may be equally reasonable.

Table 4 Patient Management Guidelines for trauma care developed by the Eastern Association for the Surgery of Trauma (located at www.east.org).

Penetrating Intraperitoneal Injuries	Prophylactic Antibiotics in Tube Thoracostomy for Traumatic Hemopneumothorax	Prophylactic Antibiotics in Open Fractures
Prophylactic Antibiotics in Penetrating Abdominal Trauma	Management of Venous Thromboembolism in Trauma Patients	Screening of Blunt Cardiac Injury
Identifying Cervical Spine Injuries Following Trauma	Identifying Cervical Spine Injuries Following Trauma—Update	Primer on Evidence Based Medicine
Diagnosis and Management of Blunt Aortic Injury	Optimal Timing of Long Bone Fracture Stabilization in Polytrauma Patients	Management of Mild Traumatic Brain Injury
Management of Pelvic Hemorrhage in Pelvic Fracture	Evaluation of Blunt Abdominal Trauma	Geriatric Trauma
Management of Penetrating Trauma to the Lower Extremity	Emergency Tracheal Intubation Following Traumatic Injury	Endpoints of Resuscitation
Evaluation of Genitourinary Trauma	Nonoperative Management of Blunt Injury to the Liver and Spleen	Nutritional Support in Trauma Patients
Pain Management in Blunt Thoracic Trauma	Management of Genitourinary Trauma	Diagnosis and Management of Injury in the Pregnant Patient
Timing of Tracheostomy in Trauma Patients	Management of Pulmonary Contusion and Flail Chest	Screening the Thoracolumbar Spine
Nonoperative Management of Penetrating Abdominal Trauma	Small Bowel Obstruction	Blunt Cerebrovascular Injury
Management of Penetrating	Stress Ulcer Prophylaxis	Neck Injuries

The Cochrane Collaboration is one of the foremost organizations using critical analysis to guide care.(7) The Cochrane Collaboration was founded in the United Kingdom in 1993 and was named after the British epidemiologist, Archie Cochrane. In the subsequent 15 years, it has spread throughout the world using a sophisticated collaborative, multi-specialty approach. It now consists of 25 centers. They have established a register of all randomized, controlled trials. Currently, there are over 150,000 trials listed. Approximately 25% of the randomized, controlled trials located by the Cochrane Collaboration cannot be found via online medical libraries such as Medline or PubMed. A major goal of the Cochrane Collaboration is to promote research to improve systematic reviews. Cochrane has established collaborative Review Groups, and they have developed a sophisticated methodology for their reviews. Fifty-two review groups have been organized. Cochrane Reviews address clinical management in essentially

all areas of medicine. The Reviews are succinct with clear recommendations. There are several Cochrane Reviews addressing areas of injury management. They are mostly, but not entirely, focused on neurologic injury and fluid resuscitation. Perusal of that website is quite worthwhile.

The Eastern Association for the Surgery of Trauma has invested heavily in their Trauma Practice Guideline Project (www.east. org). They were among the first professional organizations applying evidence-based principles for patient care. Their initial guidelines were produced in 1998, and to date they have developed 32 practice guidelines specific to trauma care (Table 4).

EVIDENCE-BASED TRAUMA CARE—THOUGHTS FOR THE FUTURE

While the rationale for practice management guidelines development now seems fairly clear, there are substantial challenges to guideline development. These include consistency and continuity in the development process. Those organizations embarking on guideline projects should establish timelines for the varied processes involved in creating the individual guidelines, and designate timing for guideline reviews to update them based on ongoing information found through literature searches to make sure they are updated. To be relevant guidelines must be considered as living documents. In order for guidelines to be useful, they also must have monitoring of their utilization and validity, and ideally, there should be coordination of clinical trials amongst organizations to make sure there is not duplication of valuable effort to ensure that scarce resources of manpower and energy are efficiently applied.

Relative to the development of evidence-based medicine for trauma, in the United States there should be coordination among the professional trauma organizations including the American Association for the Surgery of Trauma, Eastern Association for the Surgery of Trauma, Western Trauma Association, and the American College of Surgeons Committee on Trauma. Collaboration is the key to having maximum impact. The collaboration of the North American trauma organizations is envisioned in Figure 2. Ideally, the organizations would work together for evidence-based guideline development and dissemination. A schema for intra-organizational collaboration is outlined in Figure 3. Several important components of an effective process are illustrated. These include consistency in the methodology of guideline development. Coordination and continuity of the process should be established, and on-going communication among the study groups and committees from the professional organization would be necessary to avoid duplication of effort. Monitoring of utilization and validity could be done by making use of the National Trauma Data Bank and through efforts of the American College of Surgeons Committee on Trauma. Optimal development of evidence-based practice should also consider when further evidence may be required to establish guidelines.. All of this activity could be coordinated through a central office. Figure 4 is a suggested model for the application of evidence-based outcome evaluations. There are some areas in which there is already strong class 1 data available, and in that circumstance there would be no need to have further clinical trials and that data may be used to establish an appropriate guideline. When there is insufficient data
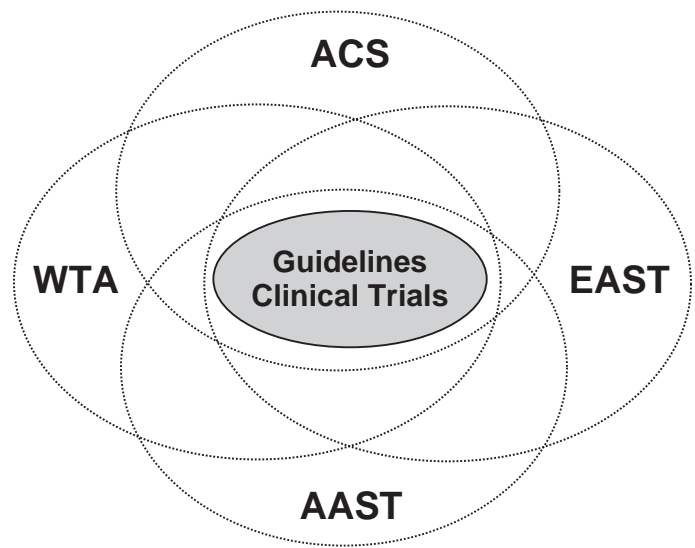
Figure 2 Proposed collaboration by North American professional trauma organizations for evidence-based medicine development through clinical trials with those results transferred into the development of practice management guidelines. (ACS=American College of Surgeons; EAST=Eastern Association for the Surgery of Trauma; AAST=American Association for the Surgery of Trauma; WTA=Western Trauma Association).
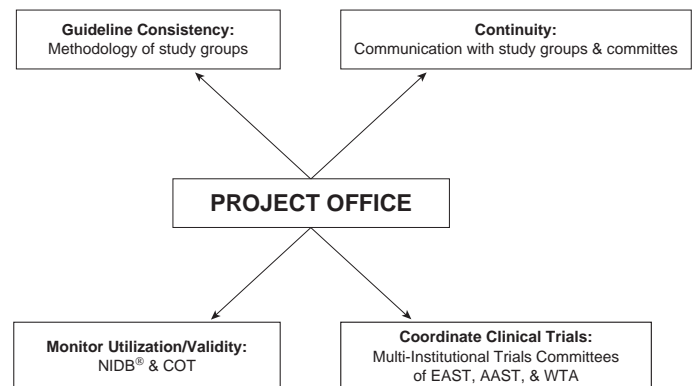
Figure 3 Overview of a management structure for collaboration by the North American professional trauma organizations to develop and utilize evidence-based processes for provision of trauma care. (NTDB=National Trauma Data Bank of the American College of Surgeons, COT=Committee on Trauma of the American College of Surgeons.

to establish a guideline of importance, randomized clinical trials could be developed through the multi-institutional trials committees of the professional trauma organizations. In instances of insufficient class 1 data, the available information could be utilized to direct hypotheses for the clinical trials based on the EBOE.

Some have questioned whether management guidelines will in fact have an impact. Is it worth the effort? I would suggest that if you build a better mousetrap, it will catch more mice. High quality management guidelines will attain traction and will substantially influence medical practice. Development of the guideline is of critical importance, but of equal significance is appropriate dissemination. This can involve print, compact disc, and web-based dissemination. Over the last decade, it has become increasingly clear that web-based dissemination is the most powerful
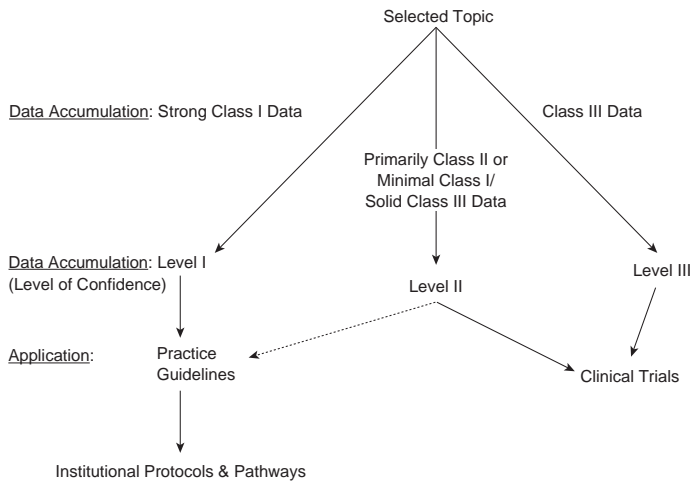
Figure 4 Suggested model for application of evidence-based outcome evaluations (EBOEs).

approach as computerization has rapidly entered bedside clinical practice. Ideally, all of these methods of dissemination will be utilized.

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1 Fluid resuscitation for the trauma patient
Michael M Krausz

A 32-year-old male is brought to the emergency room by police, 25 minutes after jumping 30 ft down unto the concrete floor. On primary survey, the airway is intact, breath sounds are equal bilaterally, systemic blood pressure (SBP) and pulse rate are 75 mmHg and 125 bpm respectively, Glasgow Coma Score (GCS) is 14 (confusion), and temperature is 36.1 °C. On secondary survey, there is a posterior scalp hematoma, tenderness over the left chest wall, left lower quadrant, lumbar spine, and pelvis. There is an open left femur fracture and bilateral ankle deformities.

The patient is immediately intubated, and a large caliber 14-gauge peripheral intravenous catheter is inserted into the antecubital vein. A subclavian central venous catheter is inserted using the Seldinger technique. As intravenous lines are started, blood samples are drawn for typing and cross-matching, appropriate laboratory analyses, and toxicology testing.

Two liters of Ringer's lactate solution and two units of non-typed, non-cross-matched O Rh⁻ packed red blood cells (PRBC) are given through a rapid infusing system with a fluid warmer. Resuscitation aims to obtain a blood pressure of 60–80 mmHg (hypotensive resuscitation).

Chest and pelvic X-rays are obtained. The chest radiograph identifies multiple right rib fractures but no life-threatening conditions such as pneumothorax or significant hemothorax. The pelvic X-ray demonstrates no acute injury. Focused abdominal sonography for trauma (FAST) is performed, which demonstrates massive hemoperitoneum.

The injured lower extremity is manually reduced and splinted. An orogastric tube is inserted to decompress the stomach, a urinary catheter is placed for assessment of urinary output and hematuria, and the patient is transported to the operating room for emergent laparotomy and repair of his broken femur.

At surgery, a large amount of blood was found in the peritoneal cavity. Tight packing of the four quadrants of the abdominal cavity temporarily controls bleeding. Fluid resuscitation is continued with PRBC, fresh frozen plasma (FFP), and platelets infusion in a 1:1:1 ratio (damage control resuscitation). Upon stabilization of the patient, the laparotomy pads are sequentially removed. A ruptured spleen and a massively bleeding liver laceration are identified. The spleen is resected, and the hepatic bleeding is controlled with a sandwich two-layer packing of the right lobe with laparotomy pads.

The end points of fluid and blood product resuscitation after bleeding is controlled are systolic blood pressure > 100 mmHg, pulse rate < 100 bpm, urine output > 50 mL/h, and continuous monitoring of central venous pressure (CVP), blood gases, base excess (BE), international rationalized ratio (INR), and serum lactate.

Upon stabilization of the patient, a thorough exploration of the abdominal cavity is performed and reveals no concealed injuries. Two closed-suction drains are left in the subhepatic region and splenic bed, and the distended abdomen is temporarily closed with a transparent "Bogota bag."

In parallel to the laparotomy, the orthopedic team realigns the fractured femur under fluoroscopy and places an external fixator. The open wounds are debrided, copiously irrigated, and dressed. A "second look" procedure is planned for 24–36 h later, for hemostasis if necessary, debridement of necrotic tissue, and removal of the laparotomy pads and drains. A definitive repair of the femur will also be performed.

The patient is transferred to the surgical intensive care unit for further fluid resuscitation, warming, and correction of coagulopathy, acidosis, and respiratory derangements. The blood pressure, pulse rate, CVP, hematocrit, blood gases, pH, urine output, BE, blood lactate, and INR are closely monitored, until his hemodynamic and metabolic parameters stabilize.

On the second postoperative day, a 'second look" procedure is performed, the laparotomy pads, drains, and "Bogota bag" are removed with no re-bleeding. The abdominal fascia is closed with continuous nonabsorbable sutures without tension and no increase in peak airway pressure. The external fixator is removed, and the fractured femur is internally nailed.

FLUID RESUSCITATION OF THE TRAUMA PATIENT/GENERAL OVERVIEW

Trauma is the fourth leading cause of death in the USA and the leading cause of death in persons below the age 40.(1, 2) Since uncontrolled hemorrhage is a major cause of death in both civilian and military trauma (2), the treatment of these casualties at the site of injury, during transportation to the hospital, and at the emergency room prior to surgical control of bleeding, remains a major issue.

Death from traumatic exsanguination usually occurs rapidly, typically in the first 6–12 h.(3) Adequate volume therapy appears to be the cornerstone of managing the trauma patient in hemorrhagic shock. After ensuring an adequate airway, oxygenation and ventilation, resuscitation is focused on appropriate and effective fluid replacement, to reverse hemorrhagic shock and restore perfusion to vital organs.

Massive intravenous volume infusion has been the mainstay of prehospital and emergency center management of traumatic hypotension in the last 3 or 4 decades.(4) The classic model of hemorrhagic hypotension used by G. Tom Shires in the 1960s and 1970s demonstrated

that a large extracellular fluid (ECF) deficit occurred in prolonged severe hemorrhagic shock which was greater than could be attributed to vascular refill alone.(4) Only the infusion of both shed blood and lactated Ringer's solution (LR) replaced the red cell mass, plasma volume, and ECF deficit. Based on this data, the advocates of early aggressive fluid resuscitation argued that the need for increased cardiac output and oxygen delivery to maintain microvascular perfusion and oxygenation exceeds any risk of accentuating hemorrhage, and therefore trauma victims in hypotensive hemorrhage should receive large volumes of fluid as early as possible. Additional studies by this group demonstrated that the prolonged period of hemorrhagic hypotension was also associated with the development of microvascular injury with marked ECF deficit, which could be corrected only by administration of isotonic crystalloids in volumes two to three times the estimated blood loss to achieve survival. This was the basis of the current well-known dogma "3 to 1 rule" for the treatment of hemorrhagic shock, which was adopted by the Advanced Trauma Life Support (ATLS) for the treatment of trauma casualties.(5) It was recommended that the early treatment of hemorrhagic shock includes primarily the control of external bleeding and early rapid intravenous administration of 2,000 mL of crystalloids through a large bore-hole catheter, followed by additional volumes of crystalloids and blood according to the patient's response. This is guided by the estimated blood loss, and evidence for adequate end-organ perfusion and oxygenation, e.g., urinary output, level of consciousness, return of normal blood pressure, pulse pressure, and pulse rate, indicating that peripheral perfusion is returning to normal.

With the development of efficient trauma and Emergency Medical Services (EMS) systems, the type, volume, and even the need for prehospital fluid treatment were challenged. Both animal (6–8) and clinical studies (9–13) demonstrated that aggressive fluid resuscitation to achieve normotension in uncontrolled hemorrhagic shock was inferior to no fluid resuscitation (dry resuscitation) (13–15 **1A**) or limited resuscitation (hypotensive resuscitation, permissive resuscitation). (16–19 **1A**) The latter resuscitation paradigms resulted in decreased rebleeding from injured blood vessels, improved hemodynamic recovery, and reduced mortality when compared with standard resuscitation. Thus, in uncontrolled hemorrhagic shock, the resuscitation-induced increased blood volume could exacerbate blood loss by increasing intraluminal pressure, relieving vasoconstriction, and/or dislodging pre-existing clots. In contrast, in controlled hemorrhagic shock, bleeding is permanently controlled (ligation, clamping, splenectomy, etc.) and cannot resume with repletion of the intravascular volume. These fundamental differences constitute the basis for the current guidelines in military as well as civilian fluid resuscitation of trauma casualties in hemorrhagic shock.(20–23, 26 **1B**)

The IDF Medical Corps Prehospital Guidelines of the Consensus Panel 2003 (26 1B) were

a. Control of bleeding is the primary most important goal in the bleeding trauma casualty. External bleeding should be immediately controlled by a direct compressing bandage or tourniquet. In internal torso bleeding causing uncontrolled hemorrhagic shock, immediate evacuation to a surgical facility is the first priority.

b. Excessive fluid resuscitation in uncontrolled hemorrhagic shock may "Pop the clot," and therefore a policy of "hypotensive resuscitation" should be adopted in order to maintain vital organ perfusion with minimal increase in blood loss.

c. In penetrating torso injuries with uncontrolled hemorrhagic shock, fluid resuscitation should be initiated only when at least one of the following parameters of Class III hemorrhagic shock is present: 1. Changes in mental status (no head injury). 2. Radial pulse became non-palpable 3. A measurable fall in systolic blood pressure below 80 mmHg.

d. In blunt or penetrating head injuries, systolic blood pressure should be maintained above 100 mmHg.

e. In rapid evacuation (less than 1 h), the "scoop and run" policy is adopted. After control of airway and breathing (A, B), the patient is rapidly evacuated to a surgical facility and fluid resuscitation is initiated en route to the hospital by aliquots of 250 mL of isotonic crystalloid (Ringer's lactate) infused until one of the above mentioned parameters is attained.

f. In extended evacuation (more than 1 h), aliquots of 250 mL isotonic crystalloid should be administered to obtain the above-mentioned parameters that are monitored every 15 minutes. When evacuation time is more than 2 h, a urinary catheter is introduced.

Currently, however, there is no universal consensus pertaining to the optimal resuscitation strategy in trauma patients. A recent empiric mathematical model in patients with uncontrolled hemorrhagic shock demonstrated that the timing of crystalloid administration with respect to intrinsic hemostasis shapes the patient's hemodynamic response. An early fluid bolus delays hemostasis and increases blood loss, while a late bolus up to 34 minutes from injury may also trigger re-bleeding (24 **C**).

Although the American College of Surgeons via its ATLS course still advocates standard fluid resuscitation, many trauma surgeons practice judicious fluid resuscitation to maintain mean arterial pressure (MAP) in the 60–80 mmHg range in uncontrolled hemorrhagic shock without traumatic brain injury. As hemorrhagic shock may worsen the initial cerebral injury by inducing global cerebral ischemia (25 **1B**), any fluid strategy in patients with combined head injury and uncontrolled hemorrhagic shock must take into account this double-edge sword. Maintaining initial MAP above 100 mmHg in spite of the anticipated increase in blood loss, (26–28 **1B**) is a prudent approach to the resuscitation of this group of patients.

OBJECTIVES OF FLUID REPLACEMENT

Hemorrhagic shock is associated with cardiovascular decompensation, reduced cellular perfusion and oxygen delivery, and development of profound lactic acidosis. If oxygen delivery is not promptly restored, cell membrane pumps fail and cellular function will not be recovered even if perfusion and oxygen delivery is later restored. Depending on the number of cells and tissues sustaining irreversible damage organ, failure and death may occur. Therefore, fluid replacement in trauma patients aims to minimize the number of irreversibly damaged cells by promptly restoring oxygen delivery to vital tissues. Because of the risk of re-bleeding in uncontrolled hemorrhagic shock, overzealous resuscitation must be avoided and only the minimal amount of fluid that ensures adequate tissue perfusion must be administered. The infused fluid may stay in the intravascular compartment or equilibrate with the interstitial/intracellular compartment.

FLUID CHOICES IN TRAUMA RESUSCITATION

Together with control of bleeding, adequate volume therapy is the cornerstone of managing hemorrhagic shock. Early infusion of crystalloid solutions, plasma, and blood are the mainstays of initial fluid resuscitation. Blood products, crystalloid (hypo-, iso-, and hypertonic) solutions, human albumin (HA), colloids (dextrans, gelatins, hydroxyethyl starch (HES) preparations), and hemoglobin-based oxygen carriers are all available to treat volume deficits.(29, 30 **1B**)

Blood

Volume resuscitation of the trauma patient requires repletion of oxygen-carrying capacity with red blood cell transfusion and restoration of intravascular volume to replace extracellular loss. Few would argue that the best resuscitation fluid is blood. It offers the advantage of volume expansion, oxygen transport, and it remains in the intravascular space for prolonged periods. Although transfusion may be necessary to improve tissue oxygenation, multiple studies have shown blood transfusion to be associated with poor outcomes including increased rate of infection, acute respiratory distress syndrome, multiple system organ failure, and death. (31, 32 **1B**) There are several disadvantages to blood as an initial resuscitation fluid. It must be cross-matched, which requires a specimen from the patient, and time to be prepared by the blood bank. Massive transfusion can cause transfusion reactions, hypocalcemia, hypomagnesemia, dilutional coagulopathy, and systemic immunosuppression. Blood-borne viral pathogens may also be transfused causing hepatitis and HIV.

In civilian trauma centers, PRBC in combination with FFP is usually used for treatment of hemorrhagic shock. In military scenarios, fresh whole blood (FWB) is also used especially when PRBC supplies were exhausted.(33) Recent studies have demonstrated that the acute coagulopathy of trauma is often present before any resuscitative efforts.(34 **1B**) This has led to an ongoing reevaluation of traditional resuscitation practices for severely injured patients, focusing on limiting the amounts of crystalloids and PRBC, and increasing the ratio of transfused FFP and platelets.(34, 35 **2B**)

Fresh Frozen plasma

FFP is plasma that is stored in a frozen state to maintain shelf-life. One unit of FFP typically has a volume of about 200 mL and contains levels of coagulation factors as found in FWB except for factors V and VIII. The risk of transfusion transmitted disease with FFP is low, but transmission of viruses and other pathogens is still possible. FFP is indicated to correct clotting abnormalities evaluated by prothrombin time, INR, and activated partial thromboplastin time. Prophylactic administration of FFP based on the number of units of blood during massive transfusion has not been recommended, but current review articles describing damage control or hemostatic resuscitation principles coupled with early coagulopathy of trauma suggest a change from this classic approach.(36, 37) In severe hemorrhagic shock with large vessel bleeding, prevention and treatment of acidosis and hypothermia is achieved by administrating FFP, PRBC, and platelets in a 1:1:1 ratio (damage control resuscitation), early use of fibrinogen, potential use of recombinant activated factor VII, and decreased emphasis on excessive crystalloid and PRBC use.(38–41 **2B**) A recent study in combat trauma patients demonstrated that FFP infusion was independently associated with in-hospital improved survival, while massive blood transfusion was independently associated with reduced survival.(42 **2B**)

CRYSTALLOIDS

Hypotonic (e.g., dextrose in water), isotonic (e.g., 0.9% saline, LR), and hypertonic crystalloids (7.5% saline solution) have to be distinguished when crystalloids are used for volume replacement. Crystalloids are freely permeable to the microvascular membrane and are therefore rapidly distributed across most of the extracellular space. Only 25% of the infused isotonic crystalloids remain in the intravascular compartment, whereas 75% extravasate into the interstitial compartment. Dilution of plasma protein concentration may also be accompanied by a reduction in plasma colloid osmotic pressure (COP), subsequently leading to tissue edema.

LR is the most widely available and frequently used balanced salt solution for fluid resuscitation in hemorrhagic shock. It is safe and inexpensive, and it equilibrates rapidly throughout the extracellular compartment, restoring the ECF deficit associated with blood loss. It is isotonic with blood and is very similar, but not identical with Hartmann's solution, the ionic concentrations of which differ. LR treatment of hemorrhagic shock is preferred over normal saline, which may on prolonged use cause hyperchloremic acidosis. LR because of its by-products of lactate metabolism in the liver may counteract acidosis, which occurs during hemorrhagic shock with impaired renal function. Because of the rapid equilibration of LR in the extracellular space, larger volumes may be required for adequate resuscitation.(43 **1B**) Dilution of plasma protein concentration may also be accompanied by reduction of plasma COP, subsequently leading to tissue edema. Generally, two to four times as much crystalloid, one volume of 5% albumin or 6% hetastarch is required to achieve the same physiologic end points.(44 **1B**)

Although the use of crystalloids has been routine for resuscitation of patients with acute blood loss, several studies have raised questions regarding the effect of resuscitation regimens on aspects of the immune response to hemorrhagic shock. It was observed by Rhee et al. (45**C**) that LR exacerbated neutrophil superoxide burst activity and increased neutrophil adherence. Also, it has been shown that aggressive fluid resuscitation was followed by increased cytokine activation including IL-1, IL-6, and TNF.(46 **2A**)

Dextrose 5% is not recommended for treatment of hemorrhagic shock. It is distributed throughout the total body water and is ineffective for replacing intravascular volume.

Hypertonic 7.5% saline solution has been used to treat hemorrhagic shock. Clinical and experimental studies have demonstrated that a small volume of hypertonic saline (5 mL/kg NaCl 7.5%) with or without dextran can be an effective initial resuscitation solution. Improved cardiovascular function was achieved on several levels: displacement of tissue fluid into the vascular compartment and plasma volume expansion, improved microvascular flow, control of intracranial pressure, vasodilation in the systemic and pulmonary circulation, reduction in venous capacitance, and positive inotropic effect on the myocardium with no deleterious effects on immune function. As the beneficial hemodynamic effects of hypertonic saline are transient, colloids such as dextran or HES were added to the solution for prolongation of efficacy.(471**1B**)

To date, 11 prospective clinical trials comparing the efficacy of hypertonic saline with standard crystalloid resuscitation have

been published in the English literature.(48) These studies demonstrated that hypertonic saline can be safely administered in trauma patients and established its superiority in reversing hypotension and reducing fluid and blood requirements compared to crystalloid solutions.

Small volume hypertonic saline (250 mL of NaCl 7.5%) was recommended by the Committee on fluid resuscitation of the Institute of Medicine of the National Academy of Sciences for the initial treatment of combat casualties.(49 **1B**)

However, the vast majority of these trials failed to demonstrate statistically significant improvement in overall survival although more favorable effects were reported in patients with severe head injury. Furthermore, many of these studies were subject to much criticism since hypertonic saline was not infused alone, but in addition to conventional crystalloid treatment.(50, 51 **1C**)

COLLOIDS

The use of colloid solutions that tend to remain in the intravascular compartment has been advocated for treatment of hemorrhagic shock. Several colloid solutions were studied in clinical practice including HA, HES, and dextran.(52, 53 **2A**)

The colloid fluid contains large-enough particles to exert an oncotic pressure across the microvascular membrane, and therefore, they have greater intravascular persistence compared to crystalloids. Albumin is the only colloid-containing particles with uniform molecular weight. A single bottle of albumin represents exposure to many thousands of donors, carrying a theoretical risk of transmission of prion causing a new variant of Creutzfeldt–Jakob disease. The other colloids are polymers and contain particles with a wide range of molecular weights. The semisynthetic colloids include dextran, modified gelatins, HES, and hemoglobin solutions. The major disadvantages of colloid infusions are anaphylactoid reactions, impairment of coagulation, and cost.

The debate comparing the use colloid or crystalloid solutions for resuscitation of hemorrhagic shock has been ongoing for several decades. Those who advocate the use of colloids argue that the administered high-molecular-weight compounds remain in the vascular space, where they maintain vascular volume by exerting oncotic pressure, and therefore reduce resuscitation volume and third spacing. In contrast, the supporters of crystalloid resuscitation claim that the microvascular injury during shock channels the oncotically active particles into the interstitium. This exacerbates the development of edema, which is much more difficult to treat with diuretics as the administered proteins or large molecules are cleared primarily through lymphatic drainage.

It is critical that the trauma surgeon be aware of the pros and cons of both the crystalloid and colloid resuscitation fluids.

Although several review articles and meta-analyses have concluded that either fluid can be used to adequately volume resuscitate the trauma patient (52, 53 **1A**), many surgeons believe that the administration of protein- or colloid-contained solutions are of little value for patients in severe shock and may even be injurious. Nevertheless, following initial resuscitation, once the endothelial integrity has partially recovered, administration of colloids could be beneficial. At that time, colloids can reduce edema in organs with tight endothelial junctions such as the skin, fat, and skeletal muscle. In contrast, they do not reduce edema in the lungs, gut, and liver, which contain large endothelial intercellular gaps.

Colloid solutions have been recommended for military use. In the military setting, weight and volume are of special concern, and the large volumes needed in isotonic crystalloid resuscitation must be transported to the field, sometimes on the back of the medical professionals. This could compromise both the fighting ability of these individuals and the field resuscitation of combat casualties.(54 **1B**)

Albumin is a naturally occurring plasma protein that is relatively expensive. It is generally accepted that albumin is safe in terms of transmission of infectious diseases except for a theoretical concern of prion transmission. There is no clear indication for its use in adult trauma resuscitation. It is still used in pediatric patients, partly because HES is not yet licensed for use in children.

Dextran is a glucose polymer that is available in two preparations of different molecular weights (6% dextran 70 and 10% dextran 40). Infusion of 1,000 mL of dextran 70 will increase plasma volume from 600 to 800 mL. The significant side effects of dextran have been coagulation abnormalities and life-threatening hypersensitivity reactions. Presently, 6% dextran 70 is used in combination with 7.5% NaCl for small-volume resuscitation of hemorrhagic shock.

Gelatines are modified beef collagens with a low molecular weight of 35 killo Dalton with a short intravascular half-life of approximately 2 h. The gelatins are supposed to be the least effective colloids with no dose limitation and are free of risk of prion transmission.

HES are high polymeric glucose compounds with different molecular weights and different degrees of substitution of hydroxyethyl to hydroxyl groups. Resuscitation with HES improved systemic circulation, microcirculatory flow, and metabolism, but thrombus formation is impaired with increased bleeding tendency.(55 **2B**)

HEMOGLOBIN SOLUTIONS

Blood is required for repletion of oxygen-carrying capacity, but it is usually not readily available in the prehospital settings because it requires refrigeration and typing. In recent years, there has been an increasing interest and progress in the development of hemoglobin-based oxygen-carrying resuscitation fluids. Such fluids are nonantigenic, carry no risk of transmitting disease, and have a prolonged shelf-life. The three main sources for hemoglobin under development are out-of-date human blood, bovine blood, and recombinant hemoglobin. Although several experimental products were clinically tested at different trial levels in the USA and Europe, none achieved market approval for human use except for one product in South Africa.(56 **2B**)

VASCULAR ACCESS

In trauma patients presenting with multiple injuries and hemorrhagic shock, vascular access must be obtained promptly. The urgency of the placement, the specific location, the size, and the number of catheters are dictated by the degree of shock, the location of injuries, the duration and rate of bleeding, and the type of injury. Access to the vascular system is obtained by insertion of two large caliber peripheral intravenous catheters, before consideration is given to a central venous line. Short-length, large-caliber

IV catheters are preferred for rapid infusion of large volumes of fluid. The location of the injury must be considered when choosing the site for venous access. Venous access should be avoided in injured limbs. When the injuries are located below the diaphragm, vascular access should be obtained in one of the tributaries of the superior vena cava preferably in the forearm or antecubital veins. In circumstances that prevent the use of peripheral veins, large caliber, central venous access, using the Seldinger technique or saphenous vein cutdown is indicated depending on the skill and experience of physician.

FLUID WARMING AND RAPID INFUSION

Fluid and blood resuscitation of trauma patients is best accomplished with large (14-gauge) intravenous catheters and effective fluid warmers with high thermal clearance.(57 **C**) All intravenous fluids given to the injured patient should be warmed to 39°C before using. The use of blood warmers is cumbersome yet most desirable in the emergency department. Hypothermia in the severely injured patient is detrimental because it shifts the oxyhemoglobin curve toward impaired peripheral oxygen unloading and increases bleeding tendency and infection.

In the unstable trauma patient with ongoing hemorrhage, the use of rapid infusion-warming systems, which can deliver more than 1 L/min with minimal drop in body temperature, is the standard of care. In uncontrolled hemorrhagic shock, rapid infusion should be started as soon as possible to achieve a blood pressure of only 60–80 mmHg until the bleeding source is controlled at surgery.

END POINTS OF FLUID RESUSCITATION

The assessment of intravascular volume and the adequacy of volume resuscitation are among the most difficult clinical challenges facing the trauma surgeon. Crude clinical parameters such as systolic blood pressure, heart rate, and urine output are inaccurate for several reasons. First, hypoperfusion can coexist with normotension until severe derangements occur (compensated shock). Second, hypotension, tachycardia, cold extremities, decreased urine output, and poor capillary refill are only present in patients who have lost at least 30% of their blood volume (Class III hemorrhage). (5 **1A**) Third, both blood pressure and heart rate are affected by anxiety, pain, and medications. CVP, central venous oxygen saturation, and the changes in CVP in response to volume loading are also relatively poor indicators of intravascular volume.(58 **2B**) Furthermore, it is unclear whether improved values of cardiac index, oxygen consumption, and oxygen delivery are valid markers of reduced morbidity and mortality. Administration of fluid predictably increases cardiac output, blood pressure, and tissue perfusion in the hypovolemic patient. Hence, it might seem logical to start rapid fluid infusion as soon as possible at the scene. However, when evacuation time is less than 1 h (usually in urban scenarios), attempts to gain intravenous access and to administer large fluid volumes at the scene may delay arrival to the hospital, which has been shown to reduce outcome in severely injured patients (the "scoop and run" vs. "stay and play" debate). Moreover, as discussed above, increasing blood pressure in patients with uncontrolled hemorrhagic shock may enhance or resume bleeding.(13, 15 **1B**)

BE—Although BE, which accurately reflects tissue hypoxia (59), has never been validated prospectively, many surgeons use it as the standard end point of resuscitation in trauma patients. BE correlates with the severity of shock, oxygen debt, changes in oxygen delivery, and the adequacy of resuscitation. It is also a good predictor of developing multiple organ failure and of survival, and it can be easily and rapidly determined in the emergency room. However, the use of BE as a useful end point of acute resuscitation is limited because it responds slowly to changes in intravascular volume and because it increases significantly only when blood pressure falls more than 50%.(59 **2B**)

Serum Lactate—Serum Lactate determination is a reliable marker of hypoperfusion in hemorrhagic shock. Lactate levels are a measure of anaerobic metabolism, secondary to inadequate oxygen delivery. The amount of lactate produced correlates with the total oxygen debt, the degree of hypoperfusion, and thus, the severity of hemorrhagic shock. Many physicians consider the patient's ability to clear lactic academia as the most suitable available end point for resuscitation. The failure to clear excess lactate levels within 24 h after hemorrhagic shock has been shown to predict poor outcome.(60 **2B**) A prospective study of 76 trauma patients demonstrated 100% survival in those who normalized their serum lactate within 24 h, 78% when normalized between 24 and 48 h, and only 14% survival if it took longer than 48 h to normalize the serum lactate.(61 **2B**) Although lactate clearance is widely used as an end point of resuscitation, the clinician should be aware of one significant pitfall in the interpretation of serum lactate levels. The concern is that occasionally hyper lactic acidosis neither correlates with traditional indicators of perfusion nor diminishes with increased oxygen delivery. One possible explanation of this observation could be that increased serum lactate often reflects increased aerobic glycolysis in skeletal muscle secondary to epinephrine-stimulated Na^+-, K^+-ATPase activity and not anaerobic glycolysis due to hypoperfusion. The half-life of lactate is approximately 3 h. Therefore, like BE, it cannot provide fast, real-time information in the trauma room.

Esophageal Carbon Dioxide Gap and **Gastric Intramucosal pHi**—The splanchnic bed is a region that is affected earliest by hypoperfusion. Therefore measuring esophageal carbon dioxide gap and gastric intramucosal pHi (62 **2B**) more closely mirrors changes in intravascular volume and may allow more rapid identification of hypoperfusion and be useful in ensuring adequate resuscitation. Current data suggest that these methodologies are not superior to serum lactate, oxygen transport, and base excess in guiding resuscitation.(63 **2B**) Therefore, the utility of pHi as the ultimate end point in the resuscitation of severe trauma patients remains controversial.

Sublingual Capnometry—This is a noninvasive addition to organ perfusion monitoring. The device consists of a sublingual CO2 sensor that directly measures mucosal pCO2. The normal levels of sublingual CO2 are 45–50 mmHg, and elevated levels suggest organ hypoperfusion. Presently, its use is rather limited.

Near-Infrared Spectroscopy (NIR)—NIR can measure pH and the redox state of pH-sensitive proteins on a continual noninvasive basis.(64) The NIR can be used to measure tissue oxyhemoglobin levels as a measure of tissue oxygen supply and mitochondrial oxygen consumption as a signal for further resuscitation.

SUMMARY

The primary treatment of hemorrhagic shock is control of the source of bleeding as soon as possible and fluid replacement (**1A**). In controlled hemorrhagic shock, where the source of blood loss has been occluded, fluid replacement is aimed toward normalization of hemodynamic and metabolic parameters (**1A**). In uncontrolled hemorrhagic shock, in which bleeding has temporarily stopped because of hypotension, vasoconstriction, and local clot formation, rapid evacuation to a surgical facility is the first treatment priority (**1A**). Restoration of circulation in this condition aims to regain radial pulse and sensorium and to maintain systolic blood pressure in the 60–80 mmHg range (hypotensive or permissive resuscitation), until the bleeding source is surgically controlled in the operating theatre (**1B**).

When evacuation time is shorter than 1 h, airway and breathing must be secured, and the patient should be transported to a surgical facility without spending precious time on introducing intravenous lines that can be attempted en route (**1A**). When the expected transport time exceeds 1 h, intravenous lines should be established and hypotensive resuscitation is continued until surgical control of the bleeding source is accomplished (**1A**).

Ringer's lactate, FFP, and PRBC transfusions are the mainstays of prehospital and in-hospital treatment of severe hemorrhagic shock (**1B**). Recent studies have demonstrated that the acute coagulopathy of trauma is often present before resuscitation efforts (**2B**). This has led to the introduction of novel resuscitation practices for severely injured patients, which focus on limiting the amount of crystalloid and PRBC given, while increasing the ratio of transfused FFP and platelets (damage control resuscitation). When massive transfusion is indicated, a PRBC: FFP: platelet ratio of 1: 1: 1 is recommended (**1B**).

The benefits of small volume resuscitation with hypertonic saline, reported in some clinical trials, have been only marginal, and indications for its use are presently limited to military scenarios where weight and volume considerations are of special concern (**2B**).

Hemoglobin-based solutions hold promise as effective resuscitation tools that may improve oxygen-carrying capacity without the storage, compatibility, or disease transmission problems associated with allogeneic blood transfusion. Phase III clinical studies have not yet proven their clear-cut advantages compared to standard resuscitation regimens (**2C**).

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Level of Evidence—Grading Recommendations

1A—Strong recommendation, high-quality evidence

1B—Strong recommendation, moderate-quality evidence

1C—Strong recommendation, low-quality or very low-quality evidence

2A—Weak recommendation, high-quality evidence

2B—Weak recommendation, moderate-quality evidence

2C—Weak recommendation, low-quality or very low-quality evidence

Chest 2006; 129: 174–81

2 Complex airway
Thomas C Mort and Joseph V Portereiko

A 20-year-old morbidly obese male is brought into the emergency department (ED) by an advanced life support ambulance after a college dormitory fire. The patient was rescued from his bedroom approximately 10 minutes after the initial alarm was sounded. He was found unconscious lying prone with heavy debris covering his upper chest and neck. He regained consciousness upon rescue and complained of increasing difficulty in breathing. Oxygen (O_2) is given via a face mask, a cervical collar applied, and the patient was placed on a long back board. Upon arrival to the ED, the patient is physically restrained by the paramedics because of combativeness. He is tachypneic and his O_2 saturation is 90%. He has difficulty phonating and his voice is hoarse. His beard and facial skin are covered by black soot, and he has a left lateral neck hematoma as well as left shoulder and chest abrasions.

INTUBATE OR NOT INTUBATE AT THE SCENE?
Multiple factors will influence this decision. Clinical factors such as the patient's current mental status and level of consciousness, the degree of respiratory distress based on respiratory rate, audible wheezing or stridor, and O_2 saturation on pulse oximetry will influence this choice. The specialty training of the first responders will have a major effect on this decision because of their ability to provide O_2 supplementation, skilled bag-mask support, available induction medications, the skill and judgment of using such medications, and finally the skill and jurisdiction to perform tracheal intubation. The distance from the scene of the accident to the medical facilities and any perceived or predicted rapid airway deterioration may alter airway management decisions. The "scoop and run" approach that is only 10 minutes away will vary widely from the physician–nurse-based treatment rendered at the scene by many emergency care provider teams based in Europe.

WHAT ARE THE INDICATIONS FOR IMMEDIATE TRACHEAL INTUBATION AT THE SCENE?
Firstly, patients are approached with the ABC's in mind (airway, breathing, circulation) and treatment of suspected inhalation injury should be instituted prior to definitive diagnosis. Humidified O_2 (100%) should be administered by mask whether or not intubation is planned. Obtaining control of the airway is indicated when significant partial or full thickness burns of the head, neck, or perioral region are present, or when any circumferential burns of the neck, acute respiratory symptoms or distress, respiratory depression, altered or progressive worsening mental or neurological status, and certainly progressive stridor, or hoarseness or air hunger are present. The logistics of the first responders' skill level and training may

dictate the immediate course of action. The rapid development of airway narrowing from edema and thermal injury compounded by tissue sloughing and airway obstruction may well outstrip the capabilities of even a well-trained emergency team at the scene.(1–4)

In the present case, the emergency medical service (EMS) providers decided not to intubate the patient based on the patient's body habitus and only mild to moderate symptoms of respiratory distress during their assessment.

WHAT ARE THE INDICATIONS FOR IMMEDIATE TRACHEAL INTUBATION IN THE EMERGENCY DEPARTMENT?
All the previously discussed indications would apply. However, assuming that the patient is without acute respiratory symptomatology upon arrival to the ED, a rapid assessment of the upper airway is warranted in nearly all cases of a suspected inhalation injury. Evaluation of the patient's external features include noting of any perioral or perinasal burns or carbonaceous debris, intraoral burns or soot, wheezing, stridor, coughing, hemoptysis, or carbonaceous sputum that may prompt formal securing of the airway. Other factors to consider would be pain control; anticipated wound/dressing care that may be debilitating to the patient, if the patient must go the operating room for escharotomies; or if there are any other significant traumatic injuries.(3, 4)

Significant carbon monoxide (CO) poisoning is another factor to consider for early intubation. An early chest X-ray that suggests infiltrates (aspiration, smoke or thermal injury) may prompt preemptive tracheal intubation if symptomatology is minimal or lacking.(1, 2) While there is no single method capable of demonstrating the extent of inhalation injury, a variety of signs and symptoms should raise suspicion. Soot in the mouth or nose, hoarseness, carbonaceous sputum, and expiratory wheezing are helpful. Carboxyhemoglobin levels are useful to document prolonged exposure within an enclosed space with incomplete combustion. The chest radiograph may be normal initially; bronchoscopy and radionuclide scanning may be useful in determining the full extent of injury.(1–4)

WHAT IS THE SIGNIFICANCE OF INHALATION INJURIES IN BURN CARE?
Inhalation injury has emerged as a significant factor in the immediate and long-term morbidity and mortality of the burn-injured patient. The advancement in burn therapy and its associated shock and sepsis has elevated the inhalational injury to a significant determinant of patient outcome.(2–4) Inhalational injury may consist of a variety of causative factors such as toxic gases, heat, intoxicant

gases, inhaled irritants, and thermal damage from smoke. Damage may arise from the heat of the inhaled smoke or the contents of the smoke itself. Pulmonary injury following inhalation stem from either smoke toxicity or CO intoxication.(5–7)

HOW DOES ONE DETERMINE IF AN INHALATION INJURY HAS TAKEN PLACE AND WHAT SHOULD BE DONE TO ASSESS THIS PATIENT'S CLINICAL PROBLEM?

History-taking and knowledge of the accident scene are key to the diagnosis. Diagnosis is supplemented from the history of a fire in an enclosed space or if there was known or suspected loss of consciousness at the scene. A longer exposure potentiates the injury. As noted earlier, physical signs and symptoms that include facial burns, singed nasal hair, perioral and intraoral soot and carbonaceous sputum may suggest an inhalational injury. Aggressive evaluation of the upper airway injury by laryngoscopy or flexible fiberoptic bronchoscopy (oral or nasal) to see the upper airway and tracheal mucosal surfaces is imperative. These can be performed in the cooperative patient if respiratory symptoms are moderate or less. Any supraglottic edema, inflammation, or carbonaceous debris in the upper airway should prompt early tracheal intubation in anticipation that edema, swelling, and tissue sloughing may progress rapidly, not only contributing to pulmonary care issue but potentially add significantly to airway management difficulties when attempting to intubate the trachea. A chest radiograph, extended arterial blood gas analysis for carboxyhemoglobin, standard pulse oximetry supplemented with carboxyhemoglobin monitored by bedside continuous pulse CO-oximetry are additional steps in determining the extent of exposure that most facilities can perform. Post-intubation bronchoscopy is warranted to not only assist in determining the extent of injury but also to benefit the patient therapeutically by allowing bronchoalveolar lavage.(6, 7)

WHAT IS THE TIME COURSE OF SYMPTOMS OF AN INHALATIONAL INJURY?

The time course will depend on a number of issues including the level of heat, inhaled chemicals or toxins, and the duration of exposure in an open or closed setting. Significant upper airway exposure leading to injury usually produces symptoms rapidly (within minutes) by evidence of airway edema (stridor) and respiratory distress. However, occasionally, symptoms may progress over several hours. Conversely, lower airway injury may initially lie dormant accompanied by a clear chest radiograph and a relative lack of symptoms (e.g., chest pain, cough, hemoptysis, shortness of breath, wheezing). Symptomatology reflecting lung dysfunction may develop over the course of 24–72 h, affording prospective recognition of inhalation injury problematic. The patient's premorbid conditions, age, and response to injury makes the verification and assessment of any injury challenging.(6, 8)

WHAT SPECIFIC DANGERS OF SMOKE INHALATION LEAD TO PATIENT MORBIDITY AND MORTALITY?

Three separate but related dangers lead to patient injury. Simply, exposure to smoke includes contact to toxic gases, heat, and particulate matter. Noxious gases, a byproduct of combustion, contribute to injury and death, especially at the fire scene. Combustion of common household items includes CO, hydrogen cyanide, sulfur byproducts, aldehydes, acrolein, ammonia, and isocyanates. The upper airway injury due to inhaled "heat," typically heated smoke in excess of 150ºC, will damage pharyngeal and laryngeal epithelium leading to mucosal edema. Direct thermal injury is typically limited to the upper airway, except in cases of steam inhalation, which may traverse below the vocal cords. Finally, smoke containing particulate matter may reach the terminal bronchioles where significant damage to the pulmonary parenchyma may occur. Mucosal edema, loss of ciliary action, altered mucous production, ulceration, inflammation, and the loss of surfactant production may lead to reactive airway disease, atelectasis, cast formation and sloughing, and ultimate airway obstruction.(2, 3, 7, 8) Shunting and ventilation–perfusion (V/Q) mismatch may be further worsened by increased capillary permeability, the onset of acute respiratory distress syndrome (ARDS), and pneumonia.

WHAT IS THE SIGNIFICANCE OF THIS PATIENT'S HOARSENESS?

The alteration in the speech resonating across the glottic complex strongly suggests that thermal and/or toxic gas inhalation may be contributing to upper airway edema and the patient should undergo endoscopic assessment of the upper airway to evaluate suspected tissue injury. It may be present in up to 50% of victims of significant smoke inhalation. Information gleamed may influence the timing as well as the method and approach for tracheal intubation. Unless history-taking reveals other information, other etiologies for hoarseness should be considered, namely neck trauma.(6, 8)

WHAT IS THE SIGNIFICANCE OF THE PATIENT'S ANTERIOR NECK HEMATOMA?

Before addressing the significance of the hematoma, one should consider its etiology: Is it actually a hematoma, a preexisting infection, tumor, and so on? Assuming the patient's disposition within the burning home shelter, it may be prudent to stabilize the neck to allow a formal evaluation of cervical spine injury. This factor, the addition of a hard cervical collar, will only add to the difficulty of airway evaluation and tracheal intubation, if required.

Is the hematoma contributing to the "difficulty breathing" and hoarseness? What are the characteristics of the hematoma, for example, midline or off midline, firm, soft, enlarging, or overlying the cricothyroid membrane or the tracheal rings? These findings may influence the method of securing the airway especially if conventional laryngoscopy proves difficult.

SHOULD THIS PATIENT UNDERGO AN UPPER AIRWAY ENDOSCOPY WHICH IS PERFORMED IF THERE ARE NO DISTINCT RESPIRATORY SYMPTOMS (COUGH, WHEEZING, SHORTNESS OF BREATH)?

It is suggested that the patient suspected of significant smoke inhalation (trapped in a confined space or who lost consciousness during a fire) with even mild facial and neck thermal injury, singed eyebrows, and nasal vibrissae or carbonaceous deposits in the nose or mouth, should undergo a screening evaluation. Though a

normal examination may be found despite a significant exposure, repeating the exam is warranted if symptoms appear thereafter. It is best to examine the patient prior to them developing upper airway (hoarseness, stridor, cough) or tracheobronchial symptomatology (dyspnea, chest discomfort, hemoptysis).(2–4, 9, 10)

> In the presented case, a decision is made to intubate the patient based on his respiratory distress, hoarseness, neck hematoma, and impending respiratory failure and airway obstruction.

HOW SHOULD THIS PATIENT'S AIRWAY MANAGEMENT BE APPROACHED?

A rapid but abbreviated assessment of airway management risk is a prerequisite in all cases except when one is forced to intervene without the opportunity to do so, for example, cardiac arrest. Elective evaluation of the patient in the operating room is certainly an inexact science as the "unrecognized difficult airway" remains a challenge.(11–14) This effect is exaggerated in the ED.(15, 16) Recognition of difficulty puts the practitioner on alert and places the patient at an elevated level of safety (preintubation preparation, positioning, equipment, and personnel acquisition augmented by a prudent and careful preplanned strategy with Plan A, Plan B, Plan C, etc.).(17–20) Unfortunately, the patient, who is not evaluated, is improperly assessed or has equivocal signs of potential airway management difficulty, and may be approached in a less safety conscious manner. This subsequently may set the stage for increased patient risk when a backup plan has not been conceived; rescue equipment is unavailable or handled by the novice or when assisting personnel capable of performing a surgical airway is not present.(17, 18) The American Society of Anesthesiologists suggests an 11-part airway assessment (Mallampati score to assess oral cavity–oropharyngeal opening, neck and mandibular range of motion, dentition, thyromental distance, shape of palate, facial and mandibular bone size and alteration, etc.) which may still lead even the seasoned practitioner to miss or underestimate the "unrecognized" difficult airway.(18, 19) This lends credence to why airway managers must be prepared to handle unanticipated difficulty in every case they encounter since our predictive capabilities are imprecise.

WHAT RISK FACTORS SUGGEST DIFFICULT MASK VENTILATION?

In the elective setting, risk factors including obesity (body mass index 26 kg/m^2), facial hair (beard), lack of dentition, age > 55 years, or history of snoring contribute to difficulty in establishing or maintaining effective O_2 delivery and carbon dioxide (CO_2) exchange during mask ventilation.(21, 22) Any obvious facial abnormality including masses or deformity, bone under- or over-development, dressings and packing, facial trauma, a hard cervical collar, and the limitations presented by a neutral head and neck position in the obese patient may add to difficulty. Additionally, using an appropriate-sized face mask, incorporating noninvasive maneuvers (jaw thrust, chin lift, oral or nasal airway placement) and offering two- or three-person ventilation effort are equally

important in successful mask ventilation.(23, 24) The experience, skill, and judgment of the airway manager/team are important factors to consider. This may impact nearly all the factors previously mentioned because lack of skill and experience may lead to a poor choice in face mask size and fit and failure to aggressively employ noninvasive maneuvers, or ask for additional assistance.

The presented case has several risk factors for difficult mask ventilation: morbid obesity, a thick beard, a hard cervical collar, and the need to keep his neck in the neutral position due to the possibility of cervical spine injury. Due to the presumed upper airway inhalational injury with the potential for evolving supraglottic edema, there is a concern regarding the effects that positioning (supine vs. semi recumbent vs. sitting upright) may have on the ability to provide effective mask ventilation. However, due to trauma concerns (potential spine injury), the patient had to be kept in a supine position. It should be noted that thermal injury of the face and neck may compromise and even prevent the application of a face mask due to severe discomfort (despite judicious use of analgesics). In this case, removal of the mask from the bag-mask assembly and allowing the patient to place their lips (if not burned) around the O_2 source may be an alternative approach.

AT WHAT POINT SHOULD THE PRACTITIONER(S) ABANDON INEFFECTIVE MASK VENTILATION?

When an anesthetized, paralyzed patient cannot be intubated, O_2 delivery and CO_2 exchange are dependent on the effectiveness of mask ventilation. A best attempt at mask ventilation should be made before abandoning the technique. If a concerted effort at rendering effective mask ventilation falls short, that is, $SpO_2 = 90–93\%$ despite optimal positioning, placement of oral and/or nasal airways, jaw thrust and chin lift combined with two- or three-person effort, then a supraglottic airway device, for example, laryngeal mask airway (LMA) should be placed or intubation could be attempted. (23) The ASA Guidelines for Management of the Difficult Airway defines difficult face mask ventilation as the situation in which it is not possible for the anesthesiologist to provide adequate face mask ventilation due to one or more of the following problems: inadequate mask seal, excessive gas leak, or excessive resistance to ingress or egress of gas.(19) These factors or conditions must be considered in light of the fact that often less-experienced and skilled providers will be tending to the patient's needs. Adequate "mask ventilation" is actually a misnomer; we actually are implying that adequate O_2 delivery is taking place rather than simply CO_2 exchange. "Adequate" is defined as maintaining $SpO_2 > 90\%$. Moreover, the difficulties presented by many trauma patients visiting the ED would create challenges for even the most seasoned and experienced providers of mask ventilation skills.

WHAT POSITIONING CONCERNS SHOULD BE CONSIDERED FOR THE PATIENT?

Proper management of the airway takes advanced planning and a concerted effort to adhere to some basic fundamentals that, if consistently practiced and employed, will improve the safety of airway care.(25, 26) Positioning the patient is extremely important and may, indeed impede or greatly ease the airway management process. If cervical spine precautions are in place, little choice is available except the neutral position (no sniffing
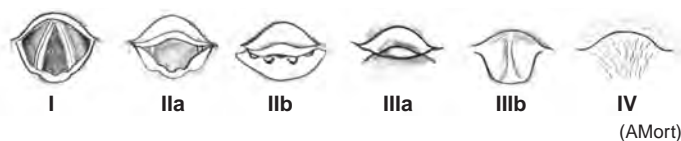
Figure 2.1 Modified Lehane Cormack laryngoscopic grading system (Yentis & Cook, 28, 29)

Legend: Left to right: Grades I, IIa, IIb, IIIa, IIIb, and IV.

position, no pillow, no cervical neck flexion, no atlanto-occipital extension). This limitation assuredly increases the risk of difficulty of visualization of glottic structures when using conventional laryngoscopy techniques.(27) Full view of the laryngeal anatomy may be restricted significantly when neutral cervical spine positioning is respected.

The mere lack of being able to bring the oral, pharyngeal, and laryngeal axes into alignment (with the laryngoscope assisting by lifting of the tongue and contents of the floor of mouth up and away) limits one's line of sight to view the laryngeal anatomy.(27) Thus, this changes a significant proportion of patients who would otherwise have a full view of laryngeal anatomy with conventional laryngoscopy (normal cervical range of motion) to a fair proportion who would have a partial (epiglottis, posterior vocal cords, arytenoids only), restricted view (tip of epiglottis only), or no view at all. The limitation of the neutral position puts the onus on the practitioner to have an alterative method of visualizing the glottis immediately available when a restricted view may be commonly encountered.

IN A GENERAL SENSE, WHAT LARYNGOSCOPIC VIEW IS COMMON IN THE EMERGENCY SETTING WHEN USING CONVENTIONAL DIRECT LARYNGOSCOPY?

A full view (Grade I) reveals all the supraglottic and glottic structures and presents little obstacle to passing of the endotracheal tube (ETT) into the trachea that may progress to only the posterior one-half of the glottic structures (Grade IIa) to the restrictive appearance of only the leading edge of the epiglottis and the most posterior components of the glottis (arytenoids, Grade IIb). Grade IIa and IIb are more difficult to pass the ETT successfully (unaided). Further, a Grade IIIa view (only the leading edge of the epiglottis visible) may be tackled blindly (much less successful) or by guiding an airway catheter, such as a bougie, via available landmarks into the trachea whereby it serves as a conduit to deliver the ETT in Seldinger fashion. A Grade IIIb (downfolded epiglottis) is often difficult to manage with a bougie and thus may require the placement of a supraglottic device such as a Combitube or LMA, fiberoptic (flexible or rigid) means, or other specialty equipment as useful alternative to conventional laryngoscopy techniques.(28–32). A Grade IV is assigned to the laryngoscopic view that essentially is "no view" of any airway structures (see Figure 2.1).

WHAT IS THE SNIFFING POSITION?

Though not applicable to all patients, most will benefit from aligning the three airway axes (oral, pharyngeal, laryngeal) to optimize one's own "line of sight" to allow guiding the ETT into the trachea.(33–38) Flexion of the cervical spine accompanied

by extension at the atlanto-occipital joint provides the basis for the "sniffing position". The flexion component can be simply accomplished by flexing the cervical spine forward by supporting the patient's head with two or three relatively firm towels (compared to a compressible pillow). Extension is provided by tilting the head backward at the atlanto-occipital joint (Figure 2.2). While the sniffing position is considered the standard approach, not all patients are best viewed in this manner, thus there will be clinical situations where only extension of the neck will provide the best view.(37, 38) Intuitively, the patient with limited cervical spine mobility (hard collar, cervical arthritis, trauma, bony abnormalities) would not be appropriate for such positioning. Optimizing head–neck–torso positioning in the obese or rotund patient is imperative for ease of management. Figure 2.3 illustrates the potential improvement from the supine/flat position to the "ramped" position.

> In the case presented, this morbidly obese patient presents with several factors that may lead to difficult mask ventilation and difficult intubation.

WHAT KEY QUESTIONS MUST ONE ASK PRIOR TO PROCEEDING?

Assuming that several key preparatory tasks have been completed (a brief airway exam, equipment and personnel acquisition, preoxygenation efforts, presence of skilled airway practitioners) a strategy for securing the airway needs to be developed. The prime considerations involve four factors: (1) assessing the likelihood and clinical impact of difficult ventilation, (2) likelihood or impact of difficult intubation, (3) the likelihood or impact of obtaining patient consent or cooperation, and (4) the likelihood or impact of difficulty establishing a surgical airway. Furthermore, one should consider the merits of management choices, for example, (1) an awake intubation technique versus asleep approach; (2) noninvasive initial approach to intubation, for example, conventional laryngoscopy versus an invasive approach, for example, surgical airway; and (3) preservation versus ablation of spontaneous ventilation (either through the administration of sedative-hypnotic-analgesics agents with or without neuromuscular blocking agents).(19, 23)

These are the primary questions and considerations that the ASA's published guidelines on the Management of the Difficult Airway suggest to the airway practitioner. The guidelines may be applied to nearly all patients yet they were designed for patients being cared for by anesthesiologists, typically in the elective operating room setting. Hence, its application to the emergency room, trauma, intensive care unit (ICU), or floor patient in acute distress, often in a state of agitation, pain, delirium, fear, helplessness, or uncooperation, without the benefit of a concise history and physical examination, may be difficult to apply wholly or in part. Brevity is key to the delivery of emergency care yet this is exactly the clinical situation that the acuity and risk is so elevated, compared to the elective situation, that careful assessment and execution of a strategy is imperative to limiting patient morbidity and optimizing safety.(19, 23)
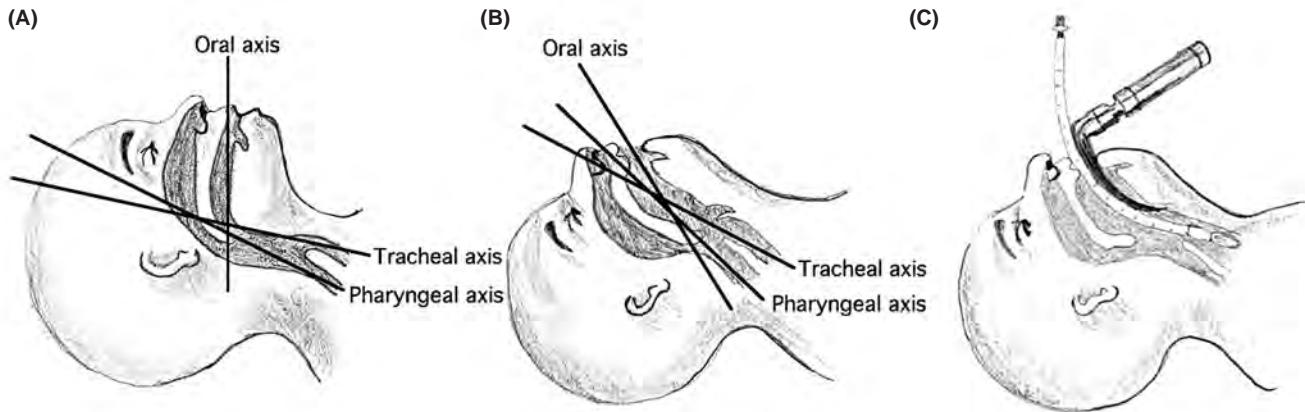
Figure 2.2 Three axes of the airway.

Legend: The three axes include the oral, pharyngeal, and tracheal vectors (a). Attaining the "sniff" position by extension at the atlanto-occipital joint and flexion of the cervical spine improves the alignment of the three axes (b). Placement of the laryngoscope with elevation of the oral content further improves this alignment (c). Courtesy of A. Mort.
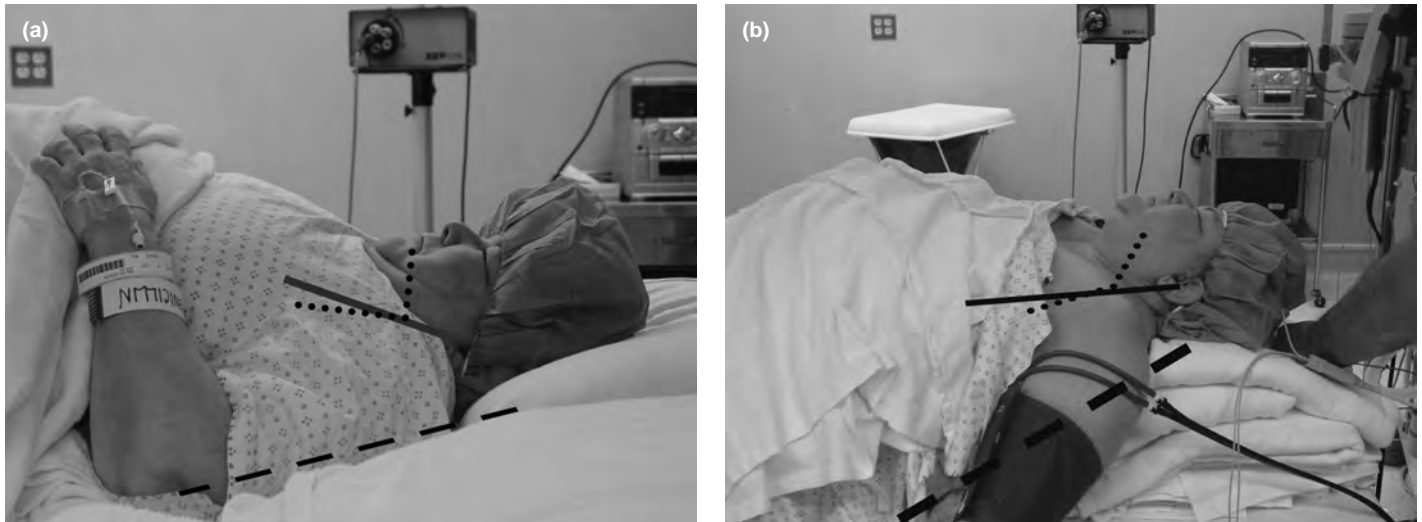
Figure 2.3 Optimizing position in the obese patient.

Legend: Supine, conventional (neutral) position in an obese patient with the limited viewing angle from the oral cavity to the larynx (dotted line) (a). Note the relative relationship of the head and neck (low) to the torso (high) which may contribute to difficulty viewing "around the corner". The "ramped" position (note tragus level to or higher than the sternum, "solid line") improves overall access by altering the torso position (dashed line). This maneuver clearing improves management of the airway by bettering mask ventilation, laryngoscopy, and the manipulation of the thyroid and cricoid cartilage (b). This simple maneuver may change a very difficult airway to a more straightforward one.

This evaluation may take a while to perform. Due to this patient's relatively rapid deterioration, is there an alterative and can this be simplified to speed up the process?

Rosenblatt devised a stepwise approach to decision making in the evaluation of the airway to assist the practitioner in developing a rational strategy for airway management.(39, 40) Five primary factors are considered and are geared toward the operating room setting. However, they may still be used by appreciating that the first question (see the following) will be answered "yes". Moreover, most trauma, ICU, or ED airway interventions assume that the patient does not have an empty stomach and thus may pose an aspiration risk. No published strategy to manage the airway is foolproof. The list is long regarding what influences such a strategy, such as patient conditions and premorbid factors; the ability to accurately evaluate

the patient's airway and provide a useful assessment of management risk; and the significant variation in the airway manager's skill level, judgment, and experience (intern, flight nurse, senior resident, surgery vs. ED vs. anesthesia, attending staff, trauma surgeon, ED attending staff, anesthesiologist, midlevel practitioner, or respiratory therapist). Nonetheless, the majority can be managed relatively safely if approached in a rational method.(39, 40) Rosenblatt suggested rapid review of five factors:

A. Is airway management necessary?
B. Is there potential for a difficult laryngoscopy?
C. Can supralaryngeal ventilation be used?
D. Is the stomach empty? (Is there an aspiration risk?)
E. Will the patient tolerate an apneic period?

Table 2.1 The Mallampati Score (I–IV) Reflects the Progressive Difficulty with Conventional Laryngoscopic Visualization (I—easy; IV—very difficult-no view).

Class I	Class II	Class III	Class IV
Hard and soft palates, uvula, pillars, tonsils all visible	Hard and soft palates, uvula, pillars visible	Hard and soft palates visible with at least partial view of the uvula or pillars	Hard palate only

Note: The two pillars are known as the palatoglossal arch (anterior) and the palatopharyngeal arch (posterior). Between these two arches is the palatine tonsil.

IS AIRWAY MANAGEMENT NECESSARY IN THE PRESENTED CASE?

Yes.

IS THERE POTENTIAL FOR A DIFFICULT LARYNGOSCOPY?

Predicting which patient will offer a challenge for mask ventilation, intubation, or both in the elective setting, is an inexact science since so many various factors may contribute to difficulty singly but most often in combination.(21, 22), Even subtle signs in an airway exam can be misinterpreted, unappreciated, exaggerated, or missed completely. (39, 40) Obviously, the majority of patients can and will be successfully ventilated with standard masking techniques followed by intubation with conventional direct laryngoscopy (DL). However, stakes are high in airway management since hypoxemia, airway trauma, aspiration, and loss of the airway have profound consequences. Furthermore, DL may be (eventually) successful but the finished product (intubation) may be accomplished with much difficulty, multiple attempts, hypoxemia, hemodynamic alterations, and more. Thus, we should be concerned about the quality of the intubation and its effects on the patient and not whether or not it was simply completed.

The presented patient appears to be at moderate to high risk for difficult laryngoscopy based on his physical features.

WHAT RAPID AND SIMPLE TESTS CAN BE PERFORMED ON THIS PATIENT TO ESTIMATE EASE OF LARYNGOSCOPY?

Bedside tests (equipment-free, straightforward) that require 15–30 s to perform include a mouth opening maneuver (to measure mouth opening and the ability to see the oropharyngeal tissues), measurement of the distance from the top of the thyroid cartilage to the mental process (mid-mandible), and an evaluation of mandibular protrusion. Most measurements can be estimated with fingerbreadth (FB) units. The first factor, the ability to open the mouth (a measure of the interincisor gap) directly correlates to the ability to place the laryngoscope orally and conversely; a narrow interincisor gap will not allow adequate manipulation of the laryngoscope. Opening to 4-cm gap or beyond (two finger breadths) is usually more than adequate. Limited opening will greatly influence one's "line of sight" when attempting to visualize the airway structures via a small mouth opening.(39) Pain, unconsciousness, intoxication, and uncooperative subjects may limit the evaluation.

The second factor is the oropharyngeal evaluation, known as the modified Mallampati test rates the degree of airway (oral cavity–oropharynx) visualization with the patient sitting upright, mouth open with the tongue extended outward (no phonation). The Mallampati test evaluates the relationship between what is seen on direct transoral visualization of the pharynx to the view on conventional laryngoscopy. The Mallampati score (I–IV) reflects the progressive difficulty with conventional laryngoscopic visualization (I—easy; IV—very difficult-no view) (Table 2.1).(33–36)

Ezri et al. suggested adding a class "0" to the I–IV scale to represent those occasional patients who can have their epiglottis visualized on the Mallampati examination.(41) They suggested that a zero class may offer an excellent laryngoscopic view. The author (Thomas C. Mort) has cared for two patients with zero class views that prove to be a limited laryngoscopic view for other reasons (limited cervical spine mobility). Thus, no test is infallible. A high Mallampati score increases the possibility of a difficult intubation but should not be used as the sole factor that determines your induction method or intubation strategy.(34–36)

The third factor, thyromental distance, easily measured in finger breadths; 3 or more (>6 cm) suggests adequate room in the "floor of the mouth" space to accommodate the tissue displaced by the laryngoscope blade. The thyromental space is bordered superiorly by the mid-mandible (mentum) and inferiorly by the hyoid-thyroid complex. If this space is large, nearly any size tongue without pathology (tumor, trauma, hematoma, radiated, adiposity, infection, edema) may be displaced into it. When the thyromental space is small, only a relatively small tongue will be displaced adequately.(36, 37) The Mallampati classification improves it predictability when the thyromental space is considered with it.(36) The ability for the patient to protrude the mandible anteriorly, the fourth factor (chin protrusion) offers information on the degree of forward displacement with laryngoscopy. Ideally, the lower incisors should be extended anterior to the upper incisors (positive sign) or the lower incisors abut or remain posterior to the upper incisors (negative sign). The accuracy of these four tests as well as others is hampered by their variable sensitivity and specificity.(39, 37)

HOW USEFUL ARE THESE TESTS IN THE TRAUMA OR EMERGENCY DEPARTMENT PATIENT?

Appreciating the mixed accuracy of many of the tests and measurements for estimating a difficult intubation in the elective setting coupled with the fact that many require active participation of the patient, leads one to understand their ultimate limitations. It may be very difficult to apply any of these tests to a patient who is supine, collared, intoxicated, comatose, belligerent, uncooperative, or traumatized.(15) Levitan et al. found that Mallampati scoring, neck mobility testing, and measurement of thyromental distance had limited application in the ED due to patient-related factors as previously stated. Not surprisingly, the bedside airway evaluations could have been effectively applied in only one-third of the noncardiac arrest ED intubations. They concluded that commonly applied airway assessment tools are limited as screening tests in the ED setting.(16) They did not, however, suggest abandoning any attempts to assess the airway prior to intervention.

Figure 2.4 Laryngeal mask airway (LMA®).

Legend: The LMA supraglottic airway has revolutionized airway management for elective and rescue care. The inflatable cuff is placed in the hypopharynx to envelope the periglottic structures to provide a seal of the airway allowing spontaneous and positive pressure ventilation. Its distal tip abuts atop the cricopharyngeal opening.

Figure 2.5 Combitube®.

Legend: The esophago-tracheal airway is a dual lumen–dual cuff airway device that may be placed in the esophagus (most commonly) or the trachea (less likely) to support ventilation and oxygenation when intubation is not possible or undesirable. A patent glottic opening must be present to allow delivery of O_2 if positioned in the esophagus.

IF ALL TESTS ARE "NORMAL" AND DO NOT SUGGEST A "DIFFICULT LARYNGOSCOPY," WHAT MAY CONTRIBUTE TO DIFFICULT VISUALIZATION AND THUS INTUBATION?

Factors may be categorized either operator-related or patient-related. Operator-related factors include suboptimal positioning, for example, the obese patient, the experience and skill of the operator, and poorly maintained or improper equipment (e.g., weak battery, poor lighting, weak suction equipment). Patient-related factors may include a floppy or enlarged epiglottis; redundant pharyngeal tissue; supraglottic, laryngeal, or subglottic edema or narrowing; tumor masses or foreign bodies; and regurgitated blood, vomitus, or secretions. An additional factor, which remains hidden even during optimal exam conditions, is lingular tonsil hyperplasia as well as redundant hypopharyngeal tissues often confounding the obese patient. This anatomical variation, enlarged lymphoid tissue at the base of the tongue, may be the most common cause of unanticipated difficult intubation, at least in the elective operative setting.(42)

You question the patient and he states "they had some trouble" with his intubation for an elective surgery last year. Conversely, he could state, "I am not aware of any trouble with my breathing passage in the past when I have had surgery."

DOES PREVIOUS AIRWAY HISTORY PROVIDE ANY USEFUL DETAILS FOR THE CURRENT INTERVENTION?

Rosenblatt suggested that a history of previous difficult airway management is more revealing than a history of an easy airway. (39, 40) Previous interventions that were straightforward and without difficulty are helpful but by no means should they dictate strategy. The known or suspected difficult airway patient typically fairs better than the unrecognized difficult airway patient since the practitioner will develop a strategy with backup plan, gather needed personnel and necessary airway equipment, and then proceed with caution. The unrecognized difficult airway patient deserves the same approach but often one's vigilance and "guard" may be let down when the airway is presumed to be uncomplicated. Thus, priority should be paid to developing a standard backup plan or strategy for all airway interventions.

Unfortunately, in the acute care setting, obtaining a history of airway difficulties may be problematic in the emergency patient. (15, 16)

An Airway Caveat

A previous difficult airway should be presumed still difficult and the previously easy airway should be considered potentially difficult (since the clinical status of the patient may have been altered drastically. Aging, weight gain, systemic ailments, trauma, and subsequent medical interventions may alter the previously "easy" airway and transform it into a clinical challenge. More acutely, this is particularly true in patients in the ICU who had an uneventful, elective tracheal intubation in the operating room under optimal conditions. Once the body has been ransacked, despoiled, pillaged, plundered, and otherwise ravaged by capillary leak syndrome, aggressive volume resuscitation, cardiopulmonary instability, upper airway manipulation via nasogastric tubes (NGTs), nasotracheal suctioning, and previous intubations, the patient's airway is typically not as straightforward as it once was. Moreover, the skills and judgment vary amongst practitioners; your easy airway may be difficult for me (differing time, equipment, setting, personnel, maladies, etc.)

WHAT IS THE BEST METHOD TO CONTROL THE AIRWAY?

Conventional DL remains the standard of care.(43–45) Tracheal intubation, beyond an oral airway, face mask, LMA, or the Combitube, provides optimal airway control, the best protection from aspiration, and affords the ability to ventilate even poorly compliant lungs (Figures 2.4 and 2.5). Due to its inherent familiarity with most airway practitioners, DL can be used to achieve tracheal intubation faster than other techniques, in most cases, unless difficulty is encountered. DL is limited by either the patient's anatomical and structural characteristic making viewing of the laryngeal structures difficult, or by the practitioners' skill, experience, judgment, choice of approach, and the use of quality equipment.

Table 2.2 Maneuvers to Obtain Optimal Ventilation.(23, 24)

Correctly sized oral airway
Bilateral nasal airways
Properly sized mask, tight fitting
Two or three person–assisted ventilation, if required
Adequate jaw thrust, chin lift, head/neck positioning

CAN SUPRALARYNGEAL VENTILATION BE USED?

Though laryngoscopy and successful tracheal intubation are the goal, intubation difficulty or failure may besiege one's best effort. The more significant question is whether or not supralaryngeal ventilation, by any means, will be effective. This is what makes airway management a two pronged challenges: Can I provide effective mask ventilation and intubate the trachea? Difficult or failed tracheal intubation should be theoretically irrelevant if adequate ventilation (and oxygenation) can be achieved by other means, primarily by face mask ventilation or secondarily, by a supralaryngeal airway device such as the LMA.(39, 40) The rationale is that if conventional DL fails yet mask ventilation is adequate, then the operator has the time (albeit, brief) and the option to recruit assistance, acquire and assemble airway rescue equipment, and execute Plan B or C.(19, 20) However, the ability to provide effective supralaryngeal ventilation in the trauma, ICU, or emergency surgical patient has not been well studied. Recently, Langeron et al. investigated the incidence and predictors of difficult mask ventilation in the elective operating room setting.(21) They identified 5% of 1,500 patients could be categorized as having a modestly to very difficult face mask airway. This group suggested that noting two of a possible five clinical factors on preoperative exam was predictive of difficult mask ventilation. We will go out on a limb and guarantee the reading audience that the rate of difficult mask ventilation in the trauma, ICU, or emergency surgical setting is no less than 5% and probably a few magnitudes higher. Preoperative clinical predictors for difficult face mask ventilation include a BMI > 26 (overweight/obesity), age > 56 years, a history of snoring or obstructive sleep apnea, and the presence of facial hair.(21)

WHAT IS CONSIDERED EFFECTIVE OR ADEQUATE VENTILATION?

Life-sustaining mask ventilation may indeed be a misnomer since ventilation represents CO_2 exchange. Realistically, O_2 delivery is the primary goal since hypoxemia is the main concern for patient care and safety. Thus, the threshold that determines acceptable ventilation (oxygenation) typically sets the SpO_2 in the vicinity of 90–93%. A concerted effort at attaining effective mask ventilation would include noninvasive maneuvers (jaw thrust, chin lift, head tilt) to improve air exchange. Mask ventilation may, however, be totally ineffective (no exchange, akin to ventilating a stone) or suboptimal where despite a concerted effort, O_2 saturation remains below the set threshold or continues to fall. The threshold may be relative since some patients may have a horrific baseline SpO_2 (any improvement may be viewed with joy) and one should rapidly decide what is acceptable for patient's well-being (Table 2.2).(23, 24)

Table 2.3 Nonemergency Versus Emergency pathways.(19)

Nonemergency Management Choices*	Emergency Management Choices*
Blind or lightwand-assisted	LMA (supraglottic airway device)
Bougie/tracheal tube introducer	Esophago-tracheal airway (Combitube)
Specialty blades (articulating McCoy)	Transtracheal jet catheter ventilation
Optical stylets (Shikani, Levitan)	Surgical airway (cricothyrotomy)
Fiberoptic techniques (rigid GlideScope, McGrath, Airtraq, Storz, Pentax ATS; flexible bronchoscope)	Rigid bronchoscope (if at bedside)
Retrograde intubation	
LMA (intubation conduit)	
Surgical airway access	

*Options include but not limited to those listed.

This patient undergoes induction with a sedative and a muscle relaxant; midline stabilization is secured following removal of the cervical collar. Conventional laryngoscopy is difficult and no attempt is made to intubate. Mask ventilation is difficult despite a three-person effort, an oral airway, and jaw thrust. O_2 saturations progressively decrease. Another laryngoscopy fails; mask ventilation is pursued but is ineffective with declining saturation. Clearly, a rapid decision is required to rescue this patient from hypoxic injury

UNDERSTANDING THERE IS A TWO PRONGED APPROACH TO AIRWAY MANAGEMENT, DOES THIS IMPACT THE CHOICE OF INTUBATION IF SUPRALARYNGEAL VENTILATION IS INEFFECTIVE?

The ASA's difficult airway algorithm (DAA) and others recognize the importance of supralaryngeal ventilation by placing it at the crossroads of the decision-making algorithm.(19, 20) Simply, if we follow induction (and assume that there is difficulty with tracheal intubation via conventional laryngoscopic means), the ability to provide effective mask ventilation will have a profound effect on subsequent efforts to secure the airway. The ability to provide life-sustaining ventilation (oxygenation) affords the opportunity to follow a "nonemergency" pathway rather than the "emergency" pathway.

Elaborate on the differences between the nonemergency and emergency pathways

The management algorithm branches into two pathways based on the ability (nonemergency pathway) or the inability (emergency pathway) to attain effective ventilation. Thus, if ventilation (oxygenation) is adequate, then several options (some rapid, some complex, some labor-intensive) are available to secure the airway.(19, 20) Conversely, if ventilation is partial or wholly ineffective (impossible), then the strategy pursued would consist of rapidly executed airway salvage techniques, primarily placement

Table 2.4 Caveats for High-Pressure Needle Jet Ventilation.(46)

1. A large bore jet catheter is best (i.e., 12 g or 14 g Jelco).

2. Following insertion of needle, aspirate air with syringe to indicate position in air column (most likely the trachea but not always so).

3. Assign one person to stabilize catheter via cricothyroid puncture site, directed caudad.

4. Continue efforts to keep upper airway open at all costs (to allow pressure egress)

5. Commence "jetting" at low pressure (5 psi) and commence upward as needed to maintain life-sustaining O_2 saturations (>80%). Do not start with the peak 50 psi level when commencing the delivery of O_2.

6. Maintain a low rate of 6–10 jet breaths per minute to allow brief insufflation and a prolonged expiratory phase (I:E=1:4–1:6).

7. Assure that chest inflation is followed by deflation to lower the risk of barotraumas.

8. "Jetting" is only a bridge, so continued efforts to secure the airway are indicated.

9. If you do not understand these concepts and have not practiced in an animal model or manikin, it may be best not to attempt it. Therefore, understand and practice.

10. Substitute an alternative low-cost, low-pressure jet system such as the Enk system (Cook Inc.) to reduce the risk of barotraumas.

of a supraglottic device such as the LMA or a infraglottic procedure (surgical access). The distinction between the nonemergency versus emergency rescue methods is typically based on the time it would take for a reasonable experienced airway manager to reliably complete the task. The retrograde wire-assisted intubation method may require 3–5 minutes to complete under optimal conditions (unlikely), thus, adequate oxygenation and ventilation must be possible for this technique to prove. Moreover, a fiberoptic technique often requires acquisition and setup of the equipment that may require a significant time. Therefore, it is not considered a viable choice when ventilation and oxygenation are not adequate. The algorithm would presume that the LMA is a viable alternative for both inadequate or failed mask ventilation, as well as play a valuable role as an intubation conduit for difficult tracheal intubation (Table 2.3).(19, 20, 40)

Following multiple intubation attempts and suboptimal mask ventilation, an LMA is placed multiple times but failed. Surgical access is not possible (lack of training). A care provider passes a 14 g IV needle/catheter through the cricothyroid membrane.

WHAT ARE THE RISKS OF PROVIDING HIGH-PRESSURE VENTILATION VIA THE CRICOTHYROID MEMBRANE?

Placement of an intratracheal catheter via the cricothyroid membrane has been a useful rescue technique in the "cannot ventilate, cannot intubate" (CVCI) situation as well as a reasonable choice deployed in the elective patient with a known difficult airway, for example, supraglottic tumor mass. It is known to be a very high-risk procedure that is practiced infrequently, instituted rarely and when not managed carefully, it may worsen an already life-threatening situation. It is imperative to understand several principles of high-pressure O_2 delivery to the tracheobronchial tree (Table 2.4).

IS THERE ANY FLEXIBILITY IN THE METHODS SUGGESTED FOR NONEMERGENCY VERSUS EMERGENCY PATHWAYS?

The DAA offerings are recommendations only, thus there is flexibility in their execution based on the availability of equipment, the skill of the practitioners, and the patient's particular airway conditions.(19, 20) Each of the emergency choices may be used in the nonemergent setting. Similarly, many of the nonemergency methods could be easily adaptable if they are immediately available at the bedside and the practitioner is well versed in his or her use of rigid fiberscopes, optical stylets, and bougie. Due to the relative complexity and number of steps required to complete retrograde intubation technique, it is only suitable as an intubation adjunct when ongoing oxygenation and ventilation efforts are successful (unless performed with the patient awake). The acquisition and setup time for the flexible fiberoptic bronchoscope puts it at a distinct disadvantage for rescuing a patient unless life-sustaining supraglottic ventilation is adequate (mask or LMA). When faced with a true CVCI situation (emergency pathway), a delay in the use of any airway device may contribute to patient morbidity or mortality. Though categorized on the nonemergent pathway, a bronchoscope that is preloaded with an lubricated ETT, defogged with the activated light source, and in the hands of a skilled operator could potentially serve the patient's needs if rapidly deployed in the emergency pathway.

This emphasizes that it is imperative to have conventional and rescue airway equipment immediately for use at the bedside whether in the ED, trauma bay, the ICU, or any remote location throughout the hospital, coupled with capable personnel. (45, 47)

Prior to induction, it is clear that the patient offers a formidable challenge for management, and there is much doubt whether mask ventilation or a supralaryngeal device could be effectively applied. Thus, induction is postponed and a new strategy is being considered.

If there is doubt, proceeding with induction may not be in the best interest of patient safety. Steps may include calling more experienced airway personnel for assistance and choosing to secure the airway either awake or sedated but maintaining spontaneous ventilation.(48) If topical anesthesia or local airway-related nerve blocks are employed, a variety of airway devices may be used; bougie insertion with DL, fiberoptic bronchoscopy, LMA, Combitube, or a rigid videolaryngoscope (Figure 2.6). Otherwise, a surgical approach (cricothyrotomy or tracheostomy) may be an option.(19, 20, 23, 24, 39, 47, 48)

YOU DECIDE TO TOPICALIZE THE PATIENT'S AIRWAY WITH LOCAL ANESTHESIA AND ADMINISTER LIGHT TO MODERATE SEDATION/ANALGESIA. INDUCTION IS FOLLOWED BY MARGINAL OR FAILED MASK VENTILATION. WHAT IS THE RECOMMENDED NEXT STEP?

If conventional mask ventilation is not successful or suboptimal despite the use of proper positioning, chin lift, jaw thrust, and the placement of appropriately sized and lubricated oral and/or nasopharyngeal airway, then rapid action to improve ventilation and O_2 delivery must be implemented. The clinical importance of the supralaryngeal airway has been distinctly transformed from
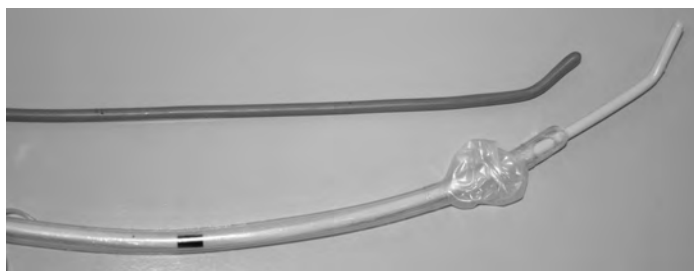
Figure 2.6 Bougie.

Legend: The tracheal tube introducer, with its 30–35º angled (Coude) tip, assists the airway manager to maneuver the bougie underneath the epiglottis and into the trachea, thus allowing a blind but guided placement of the tracheal tube by the Seldinger method.

an adjunct ventilation/intubation conduit in both emergency and nonemergency pathways in the 1993 version of the DAA.(49) The updated version of the DAA (2003) recommends the immediate use of the LMA as a logical next step when faced with failure or inadequate ventilation by mask. Previously, inadequate or impossible mask ventilation led directly to the emergency pathway. Now the LMA (or similar supraglottic airway device) is the suggested step between mask ventilation and the emergency pathway. If the LMA or supraglottic device fails, the emergency pathway is followed.(19)

THE AIRWAY TEAM ATTEMPTS FIVE LARYNGOSCOPIES WITHOUT SUCCESS. HOW MANY INTUBATION ATTEMPTS SHOULD BE CONSIDERED ACCEPTABLE BEFORE MOVING TO A RESCUE DEVICE?

The relationship between the number of laryngoscopic attempts and the incidence of airway and hemodynamic adverse events demonstrate that continuing conventional intubation maneuvers on a repetitive basis is cast in major patient morbidity and potential mortality. The recommendation put forth by the ASA's Task Force on the Management of the Difficult Airway and other of limiting laryngoscopic attempts to three, after which one should pursue the use of an advanced airway device or alternative airway rescue technique appears valid.(19, 20) However, if an experienced practitioner determines on the first best attempt that the trachea will not likely be intubated successfully using DL, then immediate deployment of a rescue airway device should be performed. Optimal intubation attempts should be based on an experienced operator, not the medical student or junior resident in training. The risk of complications in emergency airway management escalates significantly with each successful intubation attempt, especial following two attempts.(45) Thus, rapidly moving to an optional rescue method is best for patient safety. Turning away from the continued pursuit of conventional laryngoscopy techniques or allowing additional team members to do so, is not in the best interest of the patient.(45, 47)

This patient has pre-existing airway damage from the oral cavity and possibly well below the vocal cords. Mucosal edema, bleeding, and sloughing may occur without an airway intervention. Are there any additional benefits to limiting attempts?

There is substantial evidence that the incidence of complications escalates beyond two laryngoscopic attempts during emergency airway management in the remote location. The incidence of hypoxemia, esophageal intubation, regurgitation, aspiration, bradycardia, dysrhythmias, and cardiac arrest are considerably higher as attempts mount beyond two.(47, 50–53) Moreover, airway trauma resulting in bleeding, edema, and secretions may escalate with multiple intubation attempts. Thus, an airway that is in the nonemergency pathway may be shifted to an emergency pathway if edema, bleeding, and tissue trauma lead to ventilation (oxygenation) difficulties. Early use of rescue devices is recommended for an additional reason; airway edema, bleeding, and secretions may render supraglottic airway devices (LMA, Combitube) less effective or useless plus may complicate the use of fiberoptic/videolaryngoscopic equipments.(52, 53)

IS THERE ANY DISTINCTION AMONGST THE METHODS LISTED IN THE EMERGENCY PATHWAY?

The available equipment and the knowledge to execute a particular airway rescue method will often be determined by the operator involved. Firstly, the choices are clearly invasive (infraglottic) versus noninvasive (supraglottic). When obstruction or access to the airway above the vocal cords is limited, or impossible and invasive approach is indicated. Supraglottic rescue devices, for example, LMA and Combitube, require a patent glottic opening to allow O_2 delivery to the lower airway. If the supraglottic tissues are traumatized, edematous, infected, or involved with tumor, then the supralaryngeal airway devices may be ineffective, and in some cases may further injure or obstruct the trachea. Likewise, significant subglottic narrowing or obstruction may be best handled via surgical access through the cricothyroid membrane or the cartilaginous tracheal wall.(23, 24)

EXPLAIN THE INCREASED EMPHASIS ON THE LMA IN AIRWAY MANAGEMENT

The LMA is a supraglottic airway device that has transformed airway management as it serves as a superior ventilation device coupled with its role as an intubation conduit. Though neither perfect nor absolute, the LMA is able to provide a pathway to the glottis and trachea. Its appeal lies in its relative ease of use following only brief instruction and practice. Among beginners, the LMA has a higher success rate than DL and conventional face mask ventilation, and its use by experienced practitioner is consistently high as a ventilating device (80–99%).(54–57) Its use as a rescue ventilation device can be extrapolated from Parmet et al.'s (58) data as being in the range of 94%. Further, rescue ventilation in the elective operating room is extremely high (> 95%) at the authors' institution.

AS MENTIONED EARLIER IN THE SCENARIO, THE LMA WAS UNSUCCESSFUL. WHAT CONDITIONS LIMIT ITS SUCCESS?

Despite the relatively high success rate that accompanies LMA use, it may fail due to faulty insertion techniques, sizing discrepancies, or poor patient conditions, for example, trismus, lack of access to mouth, pharyngeal trauma, or edema. Though the

Figure 2.7 LMA placement in the hypopharynx.

Legend: Posterior to the arytenoids and posterior glottic structures lies the LMA that sits atop the cricopharyngeal opening (upper esophageal opening) as the LMA bowl and cuff envelop the airway structures. Note the full view of the entire periglottic region with this LMA position offering access to intubate the trachea with fiberoptic assistance. A less optimal periglottic view is common but may still be amendable to fiberoptic maneuvers for intubating the trachea.

Figure 2.8 LMA and intubating model of the LMA.

Legend: The intubating LMA (Fastrach)™ is engineered to allow both ventilation and intubation of the trachea (blindly or via fiberoptic means). The classic LMA serves both roles, yet intubation of the trachea via the LMA should be performed with fiberoptic assistance.

LMA plays a significant role in management of, for example, the patient with a fixed cervical spine, the inability to align the oral–pharyngeal–laryngeal axes is also one of its limitations. Pathological changes in the supraglottic airway and oropharynx such as infections, swelling, tumor, or traumatized tissue may limit successful placement and effective ventilation. Glottic and subglottic narrowing, scarring, stenosis, or mass effect may also lower the success rate. Likewise, a poorly compliant chest wall and lung parenchymal disease may reduce its overall effectiveness.(59–61) This patient may have several of these characteristics though many may not appear in the early setting immediately following injury.

IF THE LMA IS SUCCESSFUL AND SATISFACTORY OXYGENATION AND VENTILATION IS OBTAINED, CAN IT SERVE AS AN INTUBATION CONDUIT?

Due to the unique anatomic position when properly seated in the hypopharynx (Figure 2.7), the LMA provides a cuffed structure that surrounds and seals the upper airway thus allowing access to the larynx. The LMA allows the practitioner to bypass the palate, tongue, and upper pharyngeal wall with the distal LMA opening offering access to the supraglottic structures (epiglottis, arytenoids, true and false vocal cords). Due to possible downfolding and the medial or lateral displacement of supraglottic structures, for example, downfolded epiglottis and medially displaced arytenoid, a clear unobstructed pathway into the trachea is not guaranteed. Thus, using the standard LMA as a stand-alone intubation conduit by blindly passing an ETT is not

recommended and should be paired with the flexible fiberoptic bronchoscope. However, a variety of innovative improvements to the LMA now afford the ability to pass a specially designed ETT blindly into the trachea in a relatively high percentage (60–96.5%).(62–65) Fiberoptic guidance has a higher success rate than the blind approach and may be chosen as the initial approach or may act as a backup adjunct if the blind technique fails. Despite LMA assistance, airway secretions, blood, edema, and traumatized tissues remain obstacles to overcome. Early use is best before the airway is ravaged by additional edema and bleeding from intubation trauma.

WHAT IS THE REPORTED SUCCESS RATE OF THE INTUBATING MODEL OF THE LMA?

Ferson and a group of well-trained, seasoned practitioners used the intubating version of the LMA (Fastrach™) in a series of 254 difficult airway patients and were able to achieve successful ventilation within three attempts in all patients (Figure 2.8).(64) The vast majority of cases were elective operating room cases as opposed to the ICU, the floor, or the emergency room. The success rates for blind and fiberoptically guided intubations through the LMA-Fastrach™ were 96.5% and 100.0%, respectively.(64) The success rates cited here should be interpreted with caution. One must appreciate that these practitioners had extensive experience with the ventilating/intubating device and should be categorized as "experts," thus the average practitioner may not be capable of achieving such lofty success rates, especially in the emergency setting.

In the presented case, the intubating LMA was placed successfully, but the fiberoptic bronchoscope in the ED is found to be broken. What is the rate of success if blind intubation is attempted via the intubating LMA.

At the authors' institution, a sampling of the emergency intubation database (outside the operating room) shows a high success rate for effective LMA ventilation in 222 patients (93% within four attempts). Blind intubation was accomplished in 84% within four attempts and fiberoptic-guided ETT passage was successful in 97%. The success rate differed by level of experience and training. Despite its relatively high success rate, a backup plan is essential for patient safety. Ventilation and intubation via a supraglottic airway device is not a sole domain of the LMA as there are now a plethora of completing devices on the market that may have similar adaptability to elective and emergency use.(65–68)

In the scenario, one of the anesthesia team members suggests proceeding with a rapid sequence intubation (RSI).

The "RSI" implies a rapid transition from the awake state to unconsciousness by the administration of a sedative–hypnotic agent, for example, propofol, etomidate, or thiopental, combined with a neuromuscular blocking agent, typically the rapid–onset, short-duration succinylcholine or a nondepolarizing agent such as rocuronium. The original indication of the RSI was to minimize the risk of regurgitation and aspiration by shortening the time frame that the patient has an unprotected airway. Thus, a patient at high risk for aspiration (moderate to severe gastroesophageal reflux disease (GERD), full stomach, bowel obstruction, altered esophago–gastric–intestinal reflexes, etc.) would be induced for intubation in this fashion. However, though this original indication still exists, the new indication for an RSI in the ED, the trauma patient and remote locations outside the operating room appears to be based not on the "full stomach' rationale but on rapidly providing optimized intubating conditions. There are many authors who advocate the RSI as the safest and quickest method to secure the airway.(69–72)

The merits of the RSI in the presented case are considered.

There is no doubt that paralysis often provides better intubating conditions than sedative analgesics alone, since theoretically, there would be no patient movement including jaw clenching, swallowing, or coughing coupled with profound jaw and neck relaxation. The argument raised against paralyzing the patient is that an RSI moves the patient (and practitioner) into a position that presumes that the patient can be effectively ventilated (oxygenated) and be successfully intubated. If intubation efforts are slowed, delayed, or fail, supralaryngeal ventilation will be required to keep the patient from suffering catastrophic O_2 desaturation and its consequences. Experience demonstrates that mask ventilation may be improved (the most likely scenario) by paralysis but conversely, may be worsened by the collapse of pharyngeal tissues leading to near or total upper airway obstruction. Similarly, a spontaneously breathing patient may offer an advantage in several situations (blind nasal intubation, maintain airway patency in the obese patient or those with airway swelling/infection/abscess/mass effect).(47, 69–73)

SHOULD THE RAPID SEQUENCE INTUBATION BE THE AUTOMATIC TECHNIQUE OF CHOICE?

Protocolized medical treatment offers advantages of consistency, speed, and execution with little cerebral input. Some practitioners will prescribe the treatment (RSI) before knowing the problem (evaluating the patient's airway), because the available literature rationalizes that RSI is the safest approach to intubation. Prudence should dictate our practice, evaluate the patient and their airway, and then develop an induction strategy that takes into account the likelihood of successful supralaryngeal ventilation and tracheal intubation. If an RSI is appropriate, then perform it. Otherwise, customize the game plan to the patient's needs with a focus on safety. (This is the author's [Thomas C Mort] personal opinion).(47)

The anesthesia team tends to pursue an RSI, but questions whether succinylcholine should be used in this patient because of his acute burns.

Succinylcholine depolarizes the acetylcholine receptor that undergoes profound upregulation at the sites immediately beneath and even at distant locations from the burn. Potassium release, a normally controlled phenomenon with its administration, is exaggerated by both the upregulation of the receptors and their total number following burn injury. Based on published human studies 30 years ago, some other investigators assert that succinylcholine is safe up to 1 week after burn injury (a total of three patients within 1 week of their burn injury). Burn management has changed full circle from a conservative approach to an aggressive stance with early excision and grafting of major burn wounds.(74–77)

The upregulation of receptors that occurs in muscles beneath the area of the burn is as profound as after denervation and occurs as early as 72 h after burn. When depolarized, the receptors may exaggerate the K^+ efflux. Burn injury of a single limb (8–9% body surface area) is sufficient to cause potentially lethal hyperkalemia. Immobilization with and without prolonged administration of muscle relaxants can lead to upregulation as early as 3–4 days. Thus, succinylcholine is probably safe up to 48 h after burn injury, but it may be wise to avoid it beyond that period.(77) The author witnessed a case of hyperkalemic arrest following succinylcholine in a patient with a third degree full thickness burn (unknown to care provider) that measured less than 3% of the BSA and was well healed, 8 years post-burn.(45, 47)

In one of the many intubation attempts of this patient, the ETT is accidentally placed in the esophagus.

Esophageal intubation (EI) and more specifically, its lack of recognition, is one of the primary contributing factor in the occurrence of hypoxemia, regurgitation, aspiration, and most notably, death and severe central neurological damage. Action to reduce its ill effects by vigilant monitoring and rapid detection are considered a standard of care.(78–80) Inexperienced trainees, junior residents, and seasoned practitioners (with and without capnography) have failed to recognize EI leading to catastrophes.(78–81) Indirect clinical signs of detecting tracheal tube location (auscultation, tube condensation, chest wall excursions, reservoir
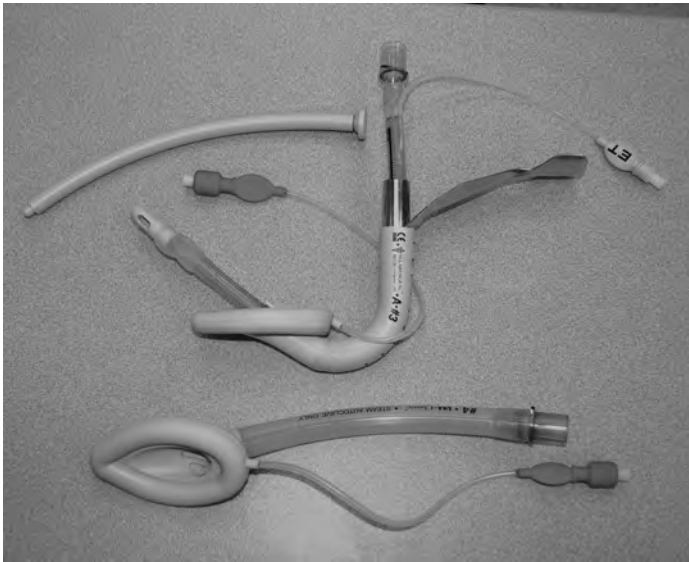
Figure 2.9 Disposable carbon dioxide detection device.

Legend: This device is attached to the tracheal tube following intubation, and carbon dioxide is detected during bag ventilation. A color change alternating with each breath (e.g., yellow↔pink) is based on pH change from the carbon dioxide being exhaled by the patient.

Figure 2.10 Esophageal detector device (EDD).

Legend: Helpful when carbon dioxide exchange is limited, for example, cardiac arrest, the bulb device is compressed, placed on the tracheal tube and then released. Rapid and full expansion of the bulb suggests the tracheal tube is within an air-filled lumen (trachea). No or slow expansion suggests that the tracheal tube is located in the esophagus. False-positives and false-negatives lower the efficacy of these devices.

bag compliance, and refilling) are imprecise and should be augmented by capnography or other similar technology. (82, 50–53) All methods have shortcomings with interpretation under normal circumstances which is eroded further in the difficult airway situation under emergent circumstances.(53, 82) Two detection methods considered "failsafe" include directly viewing of the tracheal tube between the vocal cords (impractical in up to 30% of emergency patients) and fiberoptic verification (limited by blood/secretions, experienced personnel, equipment availability), and they are failsafe on paper only.(82)

WILL MONITORS TO DETECT ESOPHAGEAL INTUBATION REDUCE THE INCIDENCE OF ENDOTRACHEAL TUBE MISPLACEMENT?

The incidence of EI, which is operator- and patient-dependent, will not be reduced but they can shorten the misplacement time. Reducing even a momentary interruption of oxygenation and ventilation in the critically ill patient can forestall disaster.(50, 51, 82) Continued gastroesophageal insufflation via the misplaced ETT increases the risk of regurgitation, hence the risk of aspiration.(50, 51) Moreover, the risk of aspiration, bradycardia, hypoxemia, and cardiac arrest is considerable in those who experience EI in the emergency situation. (51) It is imperative that a rapid, reliable, and portable technique be incorporated in the delivery of emergency airway management services.(82)

WHAT ADVANCED TECHNIQUES ARE AVAILABLE FOR ENDOTRACHEAL TUBE VERIFICATION?

End-tidal CO_2 detectors may be of two types: a disposable model; a low-cost, inline monitor based on pH-induced color change to reflect the presence of CO_2 or the reusable, battery

or electrically powered capnogram (providing an $ETCO_2$ number or LED illuminated bar) or capnography ($ETCO_2$ reading and an inspiratory and expiratory waveform).(82) The production and delivery of CO_2 requires cardiopulmonary blood flow, hence $ETCO_2$ monitoring may be rendered less precise during cardiac arrest (Figure 2.9). An inexpensive alternative based on the presence of an air column in the trachea is the esophageal detector device (EDD) (Figure 2.10). It is a bulb-syringe assembly that when attached to the ETT (tracheal position), the compressed bulb will reinflate based on the presence of air. Conversely, esophageal placement would herald no bulb reinflation based on suction applied to the esophageal wall leading to wall collapse. False-positives and false-negatives plaque both techniques. Nonetheless, immediate ETT verification (not a delayed chest radiograph) is standard of care inside and outside the operating room.(82)

> Following intubation, indirect laryngoscopy and EDD are inconclusive and interpreted with suspicion for an esophageal placement.

Based on the simple premise that the trachea bifurcates at 26–34 cm distal to the gumline in most patients, this finding can be utilized to advantage. Gentle advancement of a catheter (bougie, tube exchanger, NGT) down the ETT should lead to catheter "hang up" at the carina or the main stem bronchi and its subsequent bifurcations (Cheney's Sign). Oppositely, barring an esophageal mass or obstruction, the catheter should easily pass well past the 35-cm depth level if the ETT in placed in the esophagus.(83, 84)

Table 2.5 A Simple Airway Management Strategy.(17, 86–88)

1.	Conventional intubation	Grade I or II view
2.	Bougie	Grade III view (or Grade I & II if needed)
3.	LMA	Grade III or IV view, rescue for bougie failure, or use the LMA as a primary device (i.e., known or suspected difficult airway)
4.	Combitube	Rescue device for any failure or as a primary device if clinically appropriate
5.	Fiberscope (rigid or flexible)	Primary mode of intubation, an adjunct for LMA intubation

Intubation is difficult in this patient and various devices have been tried without much organization, prioritization, or forethought. Are there any published rescue strategies that may be applied to this burn patient?

Though none specifically exist for this patient population (burn or smoke inhalation), Combes et al. offered a straightforward, low-cost strategy for management of the airway in the operating room setting that may provide some guidance. It addressed the problem commonly found in published guidelines such the ASA's DAA that offers a long list of options to manage the airway.(17) Many practitioners review the list and deduce that it is physically impossible for anyone to be well versed and experienced in using each of the recommended methods, thus frustration as to what options would be best is apparent. Variable interest and skill may dictate equipment choice as will budget constraints regarding the purchase of a wide array of equipment. Combes developed a preplanned management schema that was based on conventional DL as the first line of management. Backup was provided by the bougie and the LMA (intubating model).(17) Following staff training on equipment use and the applied strategy, they concluded that when applied in accordance with a predefined algorithm, the gum elastic bougie and the intubating model LMA (Fastrach™) were effective in solving most problems occurring during unexpected difficult airway management that were not handled with conventional laryngoscopy methods.(17) Similar findings were suggested by the same investigators with standardization of prehospital airway management.(85) They concluded that if prehospital medical airway management is standardized and performed by trained operators, failure to intubate was rare and the incidence of difficult tracheal intubation was tempered (7.4%). A recently suggested strategy for emergency airway management of the critically ill patient outside the operating room is shown in the following.(86, 87) Patient care was compared before (no immediate access to rescue equipment) and after (immediate access to rescue equipment) the management strategy was in place. A substantial improvement in patient care was realized with the strategy: hypoxemia ($SpO_2 < 90\%$), severe hypoxemia ($SpO_2 < 70\%$), esophageal intubation, multiple esophageal intubations, regurgitation, aspiration, and the rate of bradycardia were each reduced at least by 50%. Any rescue strategy, however, should be customized to the practitioner's skill level, their access to rescue equipment, and their knowledge and competence of using such equipment (Table 2.5).(17, 47, 86, 87)

Table 2.6. Equipment for Surgical Airway access.

Necessary	Skin Prep Solution
	Scalpel (#3 handle with either #10 or # 15 blade)
	Clamp (medium size with blunt tips)
	Tracheal tube (appropriately sized ET or trachesotomy) With 10-ml syringe
	Bag valve resuscitator
	Device to secure tube to neck
Optional	Tracheal hook
	Tracheal Dilator (i.e., Trousseau)
	Gum elastic tracheal bougie
	2-O nylon sutures on cutting needle and needle driver
	Tracheal suction catheter
	Sterile gauze sponges
	25-gauge needle and 5–10 ml of lidocaine in syringe
	Sterile field drape

Mask ventilation, tracheal intubation with a bougie and LMA placement all fail. The patient is increasingly hypoxic. Is a surgical airway indicated at this point?

Rapid surgical access of the airway, cricothyroidotomy, is indicated for emergency airway control when the airway cannot be controlled by conventional or advanced equipments in a safe or expeditious manner. Conversely, surgical access may be secured as the initial approach to airway control if distorted anatomy of the oro- and nasopharyngeal and periglottic region due to trauma, edema, or tumor is found. Most often it is a clinical decision of impending loss of ability to oxygenate and ventilate the patient.(89)

WHAT ARE THE CONTRAINDICATIONS FOR A SURGICAL APPROACH TO THE AIRWAY?

Generally speaking, an absolute contraindication is the ability to pass a tube of adequate caliber into the trachea from the nasal or oral route. Relative contraindications include injury to the laryngeal complex or the cricoid cartilage with caudal retraction of the proximal trachea.

WHAT IS NEEDED TO SURGICALLY SECURE THE AIRWAY?

While many would answer that proper equipment is needed, this is only partly correct. Equally important is the knowledge and experience of performing a surgical approach which is of paramount significance. Likewise is the willingness to rapidly proceed with a surgical approach. Making a rapid decision to proceed and the timeliness of executing the cricothyroidotomy may be a major stumbling block to its own success. Specific equipment needs will be dictated by the institution and the needs of the personnel responsible for obtaining surgical access (Table 2.6).

Ideally as in an elective tracheostomy in an operating room, the shoulders of the supine patient should be raised with a set of rolled sheets or towels. This allows for a stable platform so
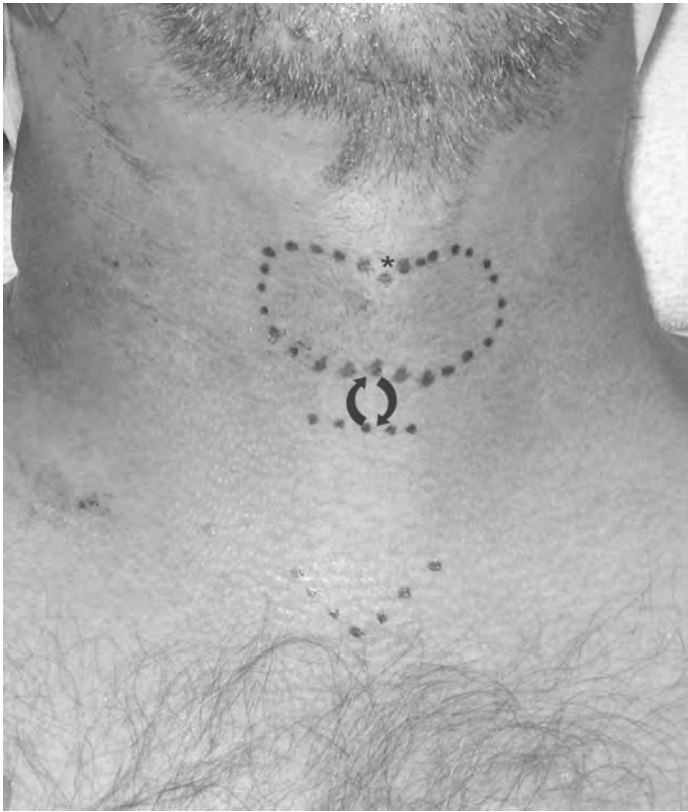
Figure 2.11 Pertinent landmarks of the anterior neck.

that the neck is in a hyperextended position. Hyperextension brings the anterior neck structures into better visualization, more clearly defines the landmarks, and opens the distance between the submental region and the suprasternal notch. Additionally it allows for easier manual stabilization of the cricoid cartilage. As with most critically injured patients, when injury to the cervical spine cannot be safely ruled out, this maneuver of hyperextension is avoided. In this case, the neck is left in neutral position as the anterior portion of any cervical spine immobilization device is removed. The attention to these factors will be much difficult by the body habitus of the described patient.

As time permits, the anterior neck should be cleansed with an appropriate skin prep solution to help prevent surgical wound infection, and a local anesthetic such as xylocaine 1% should be infiltrated into the region of the cricothyroid membrane. In many cases however the situation allows only for a rudimentary wipe of the planned incision area with a povidone-soaked sponge and no local anesthesia due to the level of consciousness of the patient. Simultaneously, attempts at oxygenation and ventilation via either bag valve mask or other means should continue.

Although the normal anatomic landmarks of the anterior neck may be obscured by local trauma, edema, burned or charred tissues, adiposity, or foreign body, essential to the safe and expeditious placement of a surgical airway is the identification of the thyroid and cricoid cartilage. This process should begin as early as possible. In most cases of emergent intubation, this is facilitated by localization of the cricoid cartilage for the Sellick's maneuver during rapid sequence induction. The cricoid cartilage is securely identified in either of two ways: (1)

identification of the suprasternal notch and palpation of the anterior tracheal rings in a cephalad direction until the first rigid structure is felt (the cricoid cartilage), (2) identification of the prominence of the thyroid cartilage (the "Adam's apple") and palpation in a caudal direction until the recess between the inferior portion of the thyroid cartilage and the cricoid cartilage (cricothyroid membrane) is palpated.(90) If time permits, marking this location with indelible ink may allow for continued awareness of its position (Figure 2.11).

WHAT SPECIFIC DETAILS OF THE SURGICAL PROCEDURE SHOULD BE REVIEWED?

The procedure will be described as being performed by a right-hand dominant operator. Left-hand dominant operators would use opposite hands as described. With the necessary patient positioning and preparation, the operator should stand at the patient's right side of the stretcher or bed near the level of the patient's neck. After palpation of the anterior neck landmarks, the operator's thumb and middle finger of his/her left hand are used to stabilize the thyroid and cricoid cartilages at their lateral junction. The tip of the index finger of this hand may also serve to reference the position of the cricothyroid membrane. It is in this space that the skin incision will be made. A vertical incision approximately 2.5 cm (1 in.) is made with the scalpel through the skin and superficial tissues overlying the cricothyroid membrane. A vertical incision is performed with a scalpel to avoid the vascular structure such as the anterior jugular veins and the recurrent laryngeal nerves which lie laterally to the midline of the anterior neck. Additionally, a malpositioned incision would most likely have been at an inappropriate level in the transverse (axial) plane. Extension of the incision in the appropriate direction easily facilitates correction. Blunt dissection down through the remaining tissue with blunt clamp such as a curved hemostat is then performed until the cricothyroid membrane is visualized. The scalpel is then used to make a horizontal incision in this membrane taking care not to penetrate too deeply and injuring the posterior tracheal wall and the posteriorly lying esophagus. A depth of no more than 1.3 cm (1/2 in.) should be achieved. The incision is extended laterally and then the scalpel is turned 180° to extend the incision in the opposite lateral direction. For placement of the endotracheal or tracheostomy tube (usually a 6.0 for male patients and a 5.0 for female patients) into the tracheal opening, a variety of techniques have been described.(91) Two of which utilize a tracheal hook to elevate the cricoid cartilage, and utilization of a Trousseau style tracheal dilator to open the membrane vertically.(92) Both allow direct visualization of the tube passing into the tracheal opening. Another is placement of a gum elastic tracheal bougie into the tracheal opening to allow for placement of the endotracheal or tracheostomy tube in a Seldinger's technique fashion.(93, 94) Elevating the cartilage is important when passing the airway over the bougie. The choice to place a tracheostomy tube versus an ETT is a matter of personal preference. Benefits of a tracheostomy tube may include: (1) the use of the obturator to assist in the placement of the tube into the tracheal opening, (2) the stability of placement since it can easily be secured to the skin of the anterior neck, and (3) the stability of connection to a bag valve mask or ventilator circuit since the connection is obviously closer to the point of fixation. *This patient presents management problems not only for conventional and advanced equipments*

but also for gaining surgical access to the airway. What difficulties are commonly encountered?

Multiple problems may arise and are typically related to: (1) a lack of familiarization with assembly, operation, and placement of a tracheostomy tube except by surgical personnel, (2) the lack of mobility of the short tube if subsequent procedures need to be performed on the patient's neck such as revision to formal tracheostomy or neck exploration. These are compounded by inability to properly position this patient, his adiposity, his beard, and the anterior neck hematoma.

COMPARE THE DIFFERENCES BETWEEN THE TWO AIRWAY CONDUITS

Benefits of an ETT may include: (1) the familiarization with the assembly, operation, and handling of an ETT by most medical personnel; (2) the beveled end of the tube facilitates placement through a tracheal opening of similar caliber; (3) the ability to manipulate through a variety of positions in a surgical field in the event of neck exploration and during revision and conversion to formal tracheostomy; (4) the ease of manipulation of a longer tube in circumstances of emergency cricothroidotomy. Difficulties, however, include: (1) the difficulties in securing a plastic tube to the neck as to prevent dislodgement and (2) the tendency to insert the tube too deep as to cause a main stem bronchial intubation. In any case, the importance of confirmation of tube position is assured with end-tidal CO_2, auscultation of breath sounds, and other clinical maneuvers or by bronchoscopic means. Further, a chest radiograph, a non-apid means to assist with airway placement, should follow surgical intubation of the trachea as it remains fairly standard post-procedure as with establishment of a nonsurgical airway.

> Locating the landmarks for the surgical airway may be difficult in this patient. What are the common complications of a surgical airway?

The immediate major complications of a cricothyroidotomy include bleeding, and perforation of the esophagus. Major bleeding from of the initial skin incision is avoided by a well-controlled, properly placed vertical incision. This will also avoid bleeding from transaction of the strap muscles and laterally lying structures including those of the carotid sheath. Minor bleeding is usually easily controlled with direct pressure or suture ligature most often after the airway has been secured. Perforation of the posterior tracheal wall and injury to the esophagus could lead to devastating complications. This is avoided by only allowing enough of the tip of the scalpel blade to enter to cricothyroid membrane as to incise it. Usually this is less than 1.3 cm (1 in.).

In the case presented, an emergency "cric" is performed in the ED. When should conversion to a tracheostomy be performed?

The timing of conversion of a cricothyroidotomy to a formal tracheostomy is dependant on a variety of variables. If the patient will have a very short-term need for ventilatory assistance (less than 48–72 h) and the patient's airway is otherwise adequate for adequate respiration, conversion may not be necessary. The cricothyroidotomy tube may be removed in a similar timing and fashion as if it were an ETT. The tracheal opening may be observed and covered with an occlusive dressing until closed. If the patient will require mechanical ventilation of a short duration (7–10 days) and the upper airway is adequate, endotracheal intubation may be performed by a variety of means including DL, fiberoptic bronchoscope assisted intubation, and so on. The cricothyroidotomy tube may be removed once the newly placed ETT is visualized in the proximal trachea (via the surgical stoma). If neither of the previously discussed expectations is reasonable, then conversion to a formal tracheostomy should be considered. This should be performed within 48–72 h or when the patient is a suitable candidate from a hemodynamic and pulmonary standpoint. In most cases, it will be possible to create the tracheotomy in its conventional position.

ARE THERE ANY SPECIFIC CONSIDERATIONS IN CHILDREN?

Cricothyroidotomy in children (less than 12 years of age) is generally discouraged. Because the prominence of the thyroid cartilage is not well developed in a child (especially before age 5), the hyoid and cricoid cartilages are the most readily palpable structures. The cricothyroid space and the diameter of the cricoid cartilage are significantly smaller is proportion relative to that of an adult. Additionally there is an associated increased risk of subglottic stenosis.

The presented patient has been in the ICU for 1 week requiring mechanical ventilation. The nurse notes that it is difficult to pass a suction catheter through the ETT and that there is a "cuff leak." In this high-risk patient, what concerns regarding ETT exchange should be recognized?

Typically, a request for exchanging an ETT is for cuff leak or rupture, ETT occlusion, ETT damaged or kinking, a change in surgical or postoperative plans, self-extubation masquerading as a cuff leak, or when the requesting team prefers a different ETT size or location.(91) Preparation for the possible failure of the exchange technique and appreciation of the potential complications is imperative.(95–97)

WHAT COMMON REASONS THAT AN ETT EXCHANGE IS REQUIRED FOR A BURN PATIENT?

ETT exchange is typically required for a leaking cuff or incompetent pilot balloon, a change in position (nasal to oral), change in size, or luminal narrowing due to secretions or kinking. Specific to the burn/inhalational victim, ETT exchange may arise from mucosal sloughing leading to luminal concretion and the need to change the ETT size to accommodate a bronchoscope.

It is deemed necessary to change the ETT of the presented patient. What methods are available to assist in ETT exchange in this difficult airway patient?

DL, a flexible or rigid fiberscope, the airway exchange catheter (AEC), and a combination of these techniques are the most common approaches.(96, 97) Proper preparation is imperative and patients should undergo a comprehensive airway exam. Access to a variety of airway rescue devices is of paramount importance in the event of difficulty with ETT exchange.(95–102)

In the presented case, conventional laryngoscopy was used in the past with little success. Is this technique useful for the ETT exchange?

DL is the most common and easiest technique for exchanging an ETT but has several pitfalls and limitations including airway

Table 2.7 Strategy & Preparation for ETT Exchange.

1. Always place on 100% O_2
2. Review patient history, problem list, medications, and level of ventilatory support.
3. Assemble conventional and rescue airway equipments.
4. Gather needed personnel (nursing staff, respiratory therapist, surgeon, airway colleagues).
5. Sedation/analgesia ± relaxants as required to optimize exchange.
6. Optimal head/neck/torso positioning.
7. Airway exam (conventional laryngoscopy, bronchoscopy, videolaryngoscopy).
8. Discuss primary/rescue strategies, role of team members, choose new ETT (warmed).
9. Suction out airway (through & around ETT).
10. Advance well lubricated large AEC via ETT to 22–26cm depth.
11. Elevate airway tissues with laryngoscope/hand, remove old ETT, pass new ETT. (incorporate use of videolaryngoscopy to optimize visualization of the exchange).
12. Remove AEC and check ETT with capnography/bronchoscopy/videolaryngoscopy.

Figure 2.12 McGrath™ portable video laryngoscope.

Legend: Portable, battery power-sourced laryngoscope with a 60º angled curved blade with an imbedded camera located toward the distal blade tip that allows one to "see around the corner" thus transforming many difficult to see airways into an improved view to assist in tracheal intubation. A disposable blade cover is attached for laryngoscopy and the video screen may be maneuvered to optimized viewing.

collapse following removal of the ETT leading to difficulty with reintubation of the trachea. This method leaves the patient without continuous access to the airway and should be restricted to the uncomplicated "easy" airway.(96, 97) Its role as a method to view the glottic opening may be severely limited and has already proven to be difficult especially in this patient. However, DL is quite helpful in elevating airway tissues to open the pathway to the trachea and reduce hang-up of the ETT as it is passed over the AEC into the airway (Table 2.7).

FORECASTING DIFFICULTY, WHAT OTHER EQUIPMENT SHOULD BE CONSIDERED FOR ASSISTING WITH THE ETT EXCHANGE?

Fiberoptic bronchoscopy is an excellent airway adjunct and offers immediate confirmation of ETT placement within the trachea and precise positioning (97, 126). Though bronchoscopy may prove difficult in the edematous or secretion-filled airway, it allows continuous airway access in skilled hands. Nonetheless, the bronchoscope may be rendered useless by unrecognizable airway landmarks, edema, and secretions. Two bronchoscopic exchange methods are commonly used. First a preloaded (ETT) bronchoscope is passed through the glottis along the side of the existing ETT if adequate room exists. Second, the old ETT may be backed out of the trachea over an AEC, then the preloaded bronchoscope is advanced into the trachea followed by advancement of the new ETT into the airway. Rigid fiberscopes (Bullard, WuScope, Upsher, Airtraq, McGrath, and GlideScope) are very useful for visualizing the otherwise difficult airway during the exchange by offering the ability to "see around the corner" and allow precise positioning of the ETT, affording ETT turning and manipulation to reduce hang up on periglottic structures, for example, arytenoid, and confirms trachea placement of the new ETT.(102) These devices may prove to be a major advancement in patient safety. Moreover, the outstanding visualization provides the opportunity to teach other airway practitioners the art and science of the ETT exchange in "living color" (Figures 2.12–2.15).

Figure 2.13. GlideScope™ video laryngoscope.

Legend: Glide Scope offers both disposable video baton covers or a reusable intubation blade that offers improved visualization of the airway compared to conventional laryngoscopy methods.(30)

SHOULD AN AEC PLAY A ROLE IN THE PATIENT'S EXCHANGE?

The AEC incorporates the Seldinger technique for maintaining continuous access to the airway, a pivotal component of

(a)

Oral axis

Oral axis

Tracheal axis

Pharyngeal axis

Tracheal axis

Pharyngeal axis

Line of sight

(AMort)

(b)

Conventional laryngoscope

GlideScope videolaryngoscope
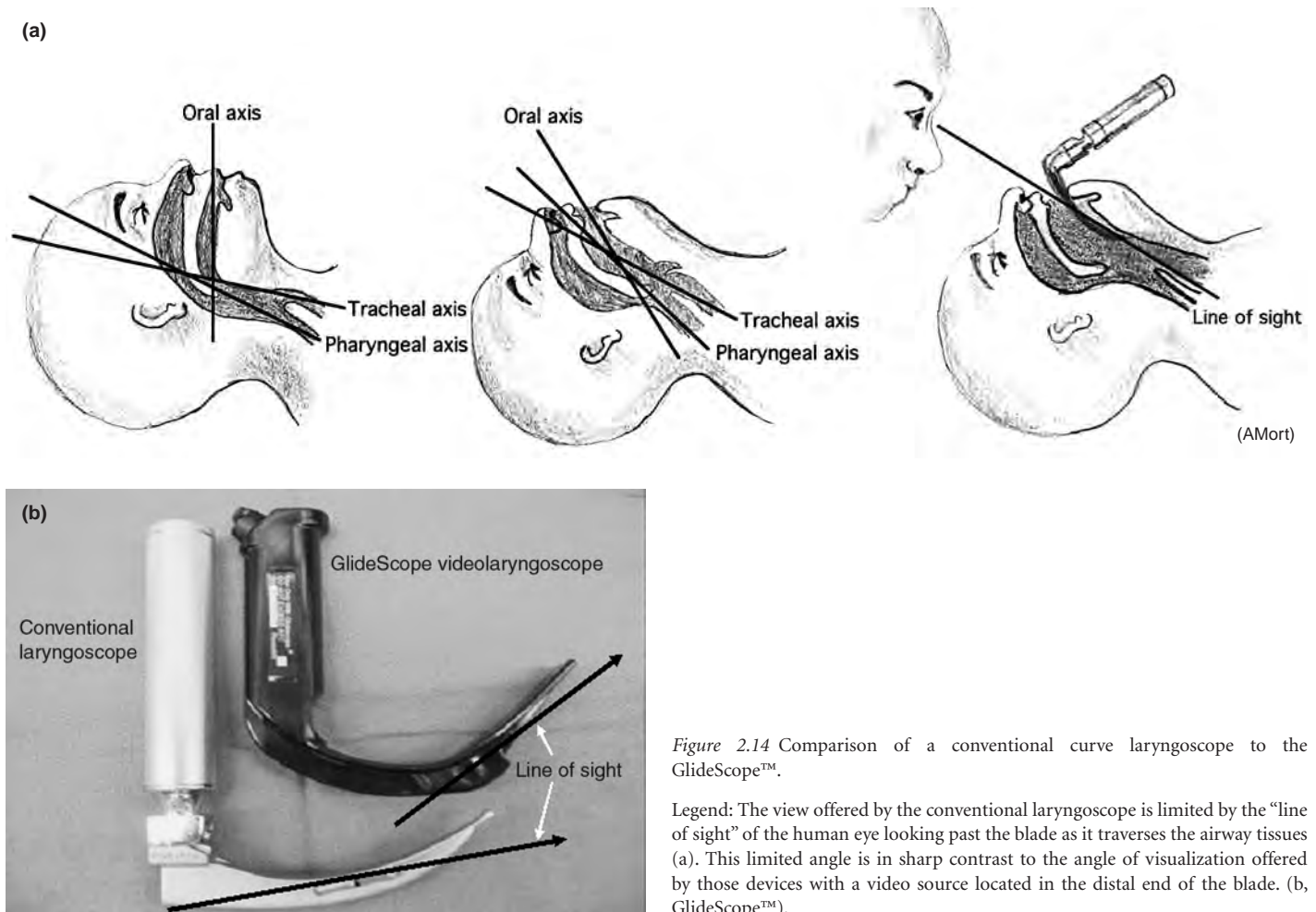
Line of sight

Figure 2.14 Comparison of a conventional curve laryngoscope to the GlideScope™.

Legend: The view offered by the conventional laryngoscope is limited by the "line of sight" of the human eye looking past the blade as it traverses the airway tissues (a). This limited angle is in sharp contrast to the angle of visualization offered by those devices with a video source located in the distal end of the blade. (b, GlideScope™).

Figure 2.15 The potential improvement in viewing the laryngeal anatomy.

Legend: A previous attempt with conventional laryngoscopy revealed a Grade IV view (no view). Videolaryngoscopy offers this view of the intubated glottis.

airway management safety. Strategy and preparation are the keys to successful and safe exchange (see Table 2.8 and 2.9). Proper sizing of the AEC to best approximate the inner diameter of the ETT will allow a smoother replacement. Chin lift–jaw thrust maneuver and/or laryngoscopy will assist in the passing of a well-lubricated

warmed ETT that may need to be rotated 90° counter clockwise to reduce glottic impingement. A larger diameter AEC is best in passing an adult-sized ETT. Minimizing the luminal gap between the ETT and the AEC is important for ease of exchange. Various AEC exchange techniques may be customized to assist the practitioner to tackle individual patient characteristics.(96–102)

Let us proceed with the exchange following the suggestions in Table 2.9. Our patient is properly positioned and placed on 100% O_2; conventional and advanced rescue airway equipment is assembled, the airway is suctioned; and the airway team members (nursing, respiratory therapy, airway managers) review their roles. A DL-assisted ETT exchange over an AEC proceeds. During the removal of the old ETT, the AEC moves out of the airway unbeknownst to the team. The new ETT is passed (blindly) 100% over the AEC. No $ETCO_2$ is detected and the patient rapidly desaturates to the low 60's. DL reveals "no view". The ETT is removed and mask ventilation is attempted but is very difficult with further reduction in the saturations leading to a bradycardic rhythm. Rapidly, the team places an LMA with success, and O_2 saturation rises to the low 90's. Once stable, the LMA is exchanged to the intubating LMA and a fiberoptic-assisted intubation takes place via the LMA.

Table 2.8 Suggested Guidelines for Maintaining Presence of AEC.

Difficult airway only, no respiratory issues, no anticipated airway swelling	1–2 h
Difficult airway, no direct respiratory issues, potential for airway swelling	>2 h
Difficult airway, cardiopulmonary issues, multiple extubation failures	>4 h

Table 2.9 Can you outline the method of AEC-assisted extubation of the difficult airway?

Suggested Extubation Procedure for the Difficult Airway Patient
Access to advanced airway rescue equipments.
Access to personnel (respiratory therapist, nursing staff, surgical airway colleagues).
Prepare circumferential tape to secure the airway catheter after extubation.
Sit patient upright, discuss with patient extubation plan.
Suction internal and external to ETT.
Pass generously lubricated AEC to 23–26 cm depth.
Remove the ETT while maintaining the AEC in its original position.
Wipe excess lubrication/secretions from the AEC prior to taping.
Secure the AEC with the tape (circumferential), mark AEC "airway only."
Apply O_2: nasal, mask, or humidified O_2 via AEC (1–2 l/min, short term only).
Maintain NPO, provide pulmonary toilet.
Assure availability of smaller caliber ETT for reintubation, if needed.

Exchange is a simple concept but not a simple procedure as hypoxemia or esophageal intubation, and loss of the airway may occur. The decision on the method of exchange is based on known or suspected airway difficulties, equipment choices, and most significantly, the experience and judgment of the clinician. It is recommended that continuous airway access be maintained in all but the simplest, straight-forward airway situations.(19, 20, 97, 100) Best intentions and meticulous preparation for patient care does not guarantee a smooth ETT exchange. However, the team's effort to have a difficult airway cart is immediately available and knowing how to use its contents proved life-saving in this instance.

> The presented patient is intubated following multiple attempts with accessory airway devices. He is now ventilated for 17 days due to ARDS and pneumonia. He is receiving aggressive diuresis to reduce his total body edema. He is weaned to 5-cm continuous positive airway pressure (CPAP) and tolerates a 6-h trial, is awake and lucid, has good pain control, and is anxious to have the ETT removed. How should the patient's airway be approached for extubation?

Airway management also constitutes maintaining control of the airway into the postextubation period, thus the known or suspected difficult airway patient should be evaluated in regard to factors that may contribute to their inability to tolerate extubation. Following fulfillment of your extubation criteria from mechanical ventilation, a review of medical and surgical conditions, previous airway interventions, an evaluation of the airway and formulation of a primary plan for extubation, and a rescue plan for intolerance is essential.(19, 95–97) Reintubation, immediately or within 24 h, may be required in up to 25% of ICU patients.(103–107) Measures to avert reintubation such as noninvasive ventilation for those at highest risk for extubation failure is effective in preventing reintubation and may reduce mortality rate if done so upon extubation.(95–97) Factors beyond routine extubation criteria that may be helpful in predicting failure include neurological impairment; previous extubation failure; secretion control; and altering metabolic, renal, systemic, or cardiopulmonary issues.(97, 103–110)

LIKE AN INTUBATION STRATEGY, SHOULD THERE BE AN EXTUBATION STRATEGY?

Yes. An extubation strategy should be developed which allows the ability to (1) support ventilation and oxygenation of the patient whilst the patient is being prepared for reintubation and (2) allow reintubation in a timely manner. (19, 95–97, 111) The practitioner should assess the patient's risk on two levels; the patient's predicted ability to tolerate the extubated state (severity of cardiopulmonary pathology coupled with other systemic influences, for example, mental status, metabolic balance, and so on, and ability (or inability) to reestablish the airway if reintubation becomes necessary (95–97, 112–116)

The anesthesia team notes that the patient does not have a "cuff leak".

Hypopharyngeal narrowing from edema or redundant tissues, supraglottic edema, vocal cord swelling, narrowing in the subglottic region, of any etiology, may contribute to the lack of a cuff leak. (117–120) Too large a tracheal tube in a small airway should be considered. A higher risk of postextubation stridor or the need for reintubation is more prevalent in those without a cuff leak, in women and patients with low Glasgow Coma Scale scores.(118–121) Determining the etiology for the lack of a cuff leak may allow one to direct patient care as individuals may remain intubated longer than is required or receive an unneeded tracheostomy.(117–121) If airway edema is the culprit, steps to decrease airway edema include elevation of the head, diuresis, steroid administration, minimizing further airway manipulation, and "time".(122–127)

"Cuff leak test" methodology and its interpretation vary by institution and by the operator. Thus, universally accepted criteria is lacking since testing to predict successful extubation is inconclusive.(119–122) A simple but nonquantitative method involves auscultation for a audible cuff leak with or without a stethoscope following deflation of the ETT cuff coupled with the delivery of a manual or machine-derived tidal volume. More precisely, measurement of the cuff leak volume by calculating the average difference between inspiratory and expiratory volume while on assisted ventilation and expressing it as an absolute volume or percentage may offer more quantitative value.(118, 129) The percentage volume will vary with the tidal volume administered during the test (8 ml/kg vs.10–12 ml/kg) but several authors have found an absolute volume leak < 110–130 ml (118, 119) or 10–24% as helpful in predicting postextubation stridor.(118–121, 129)

Following extubation, the patient demonstrates inspiratory stridor and marked respiratory efforts.

Stridor reflects the air turbulence typically caused by luminal narrowing within the airway. Edematous or traumatized supraglottic tissues, swollen or damaged vocal cords, and subglottic narrowing are just a few of the etiologies that may contribute to stridor. Postextubation stridor has been associated with an increased risk of reintubation. Determining the cause for stridor is important to assist in directing a care plan. Postextubation administration of nebulized racemic epinephrine may help reduce periglottic edema and the use of a helium–O_2 blend may reduce turbulent air flow and ease patient work of breathing.

Single or multiple dose steroids may reduce postextubation airway obstruction in pediatric patients depending on dosing protocols, patient's age, and duration of intubation.(127) Steroid use in adult administered 6 h prior to extubation may reduce postextubation stridor and the need for reintubation in critically ill patients.(104, 127–129)

BESIDES THE CUFF LEAK TEST, HOW CAN THE PATIENT BE ASSESSED FOR EXTUBATION RISK?

The cuff leak test provides little direct data regarding what is the status of the periglottic edema, if any and fails to pinpoint the level of obstruction (supraglottic vs. glottic vs. subglottic). Evaluation of the hypopharyngeal structures and supraglottic airway to assess airway patency, resolution of edema, swelling, and tissue injury may need to be performed. Conventional laryngoscopy is a standard choice for evaluation but often fails due to a poor "line of sight". Comparing the laryngeal view of a non-intubated to an intubated glottis is inconsistent.(130) Flexible fiberoptic evaluation is useful but may be limited by secretions and edema.(131) Advanced rigid laryngoscopes, videolaryngoscopy, and other indirect visualization techniques (seeing optical stylet) that allow one to see around the corner are especially helpful.(132, 133)

WHAT METHODS ARE AVAILABLE FOR A CONTROLLED EXTUBATION OF THE TRACHEA?

Typically, the flexible bronchoscope, a supraglottic airway device (LMA), or an airway exchange catheter is a commonly applied method. The bronchoscope is useful for periglottic assessment following extubation but requires advanced skills and minimal secretions. It offers only a brief moment for airway assessment upon extubation but will allow reintubation of the trachea if the operator is skilled and the airway remains patent.(131, 134–137) The LMA offers the ability for fiberoptic-assisted visualization of the supraglottic structures while serving as a ventilating and reintubating conduit.(138–139) Conversely, the AEC allows continuous control of the airway after extubation but does not offer any airway visualization. It is well tolerated in the vast majority of patients and serves as an adjunct for reintubation and oxygen administration.(95–97, 112–115)

FOLLOWING EXTUBATION OF THE DIFFICULT AIRWAY PATIENT, HOW SHOULD THEY BE MONITORED?

Observation in a monitored environment with experienced personnel (ICU, PACU) should be given top priority, as should the immediate availability of difficult airway equipment in the event of extubation intolerance.(95–97)

SUMMARY TABLE OF EVIDENCE-BASED RECOMMENDATIONS

Fiberoptic airway evaluation following smoke/noxious gas/fire exposure	1B
Intubation with smoke/noxious gas/fire exposure (all patients)	2C
Intubation with smoke/noxious gas/fire exposure (select patients)	1B
Bag-mask ventilation	1A
Bougie-assisted tracheal intubation	1B
Safety of LMA (supraglottic airway device)	1A
LMA-assisted ventilation-elective situation	1A
LMA-assisted ventilation-emergency situation	1B
LMA-assisted intubation-elective situation	1A
LMA-assisted intubation-emergency situation	1C
Combitube used as a rescue airway device	1B
Fiberoptic bronchoscopy-elective use	1A
Fiberoptic bronchoscopy-emergency/rescue use	1C
Emergency surgical airway access	1B
Videolaryngoscopy-elective situation	1B
Videolaryngoscopy-emergency/rescue situation	1C
Efficacy of extubation strategy	1C
Tracheal tube exchange methods	1C

HOW LONG SHOULD THE AEC BE LEFT IN THE PATIENT'S TRACHEA TO ASSURE A "REVERSIBLE EXTUBATION"?

There is no evidence-based literature to support a rigid timeframe for maintaining an indwelling AEC. Clinical judgment and the patient's cardiopulmonary and other systemic conditions combined with the airway status should guide the clinician in establishing a reasonable time period for maintaining a state of "reversible extubation" with the indwelling AEC (see Tables 2.8 and 2.9).(95, 112, 113, 115)

Airway management in the burn victim, as with any critically ill patient, is an evolving process that may be straight-forward to life-threatening in character. The timing of intervention will be dictated largely by the degree and duration of smoke, noxious gas, and fire exposure and the extent of containment. Airway management is a continuum ranging from simple O_2 and bronchodilator administration, to intubation, through to the vulnerable time in the postextubation period. The critically ill burn victim necessitating airway intervention may pose considerable challenges for the airway management team.

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3 Major blunt head injury
Brian Hood, Leo Harris, and M Ross Bullock

CLINICAL VIGNETTE

A 64-year-old male with a history of coronary artery disease (CAD), hypertension (HTN), and atrial fibrillation (A-fib), whose medications include warfarin and clopidogrel, is found unresponsive at the base of a stairwell by family members. The initial Glasgow Coma Score (GCS) at the scene by EMS personnel is 4T (E-1, M-2, V-1). Primary survey reveals a right frontal scalp laceration and abrasions to the right shoulder, right ribs, and hip. The patient is intubated in the field and arrives at the Trauma Center on a backboard with a cervical collar in place. Chest and pelvic X-rays are negative for traumatic pathology and show proper position of the endotracheal tube. Laboratory analysis reveals only an elevated PT with an INR of 3.4. A brief neurological examination discloses pupils that are 3 mm, equal, round and reactive to light, no spontaneous eye-opening, and decerebrate posturing to noxious stimulus. The patient is hemodynamically stable, and there are no other signs of systemic injury. Several large bore intravenous catheters are inserted and normal saline is continued at 100 cc/h. The FAST examination is completed by the Trauma Surgeon and is unremarkable. The patient is transported to the CT suite. Cervical spine imaging reveals degenerative changes without evidence of soft tissue swelling, mal-alignment, fracture, or subluxation. Non-contrast-enhanced CT of the brain is significant for a large right fronto-temporal contusion measuring 5 cm × 3 cm × 6 cm, with 8 mm of midline shift (MLS), diffuse traumatic subarachnoid hemorrhage, cerebral edema, and several areas of petechial hemorrhages consistent with diffuse axonal injury.

EVALUATION OF THE PATIENT WITH POTENTIAL TBI

Evaluation and stabilization of the potential head injured patient begins upon arrival of Emergency Medical Services to the scene.

Every scene, independent of the potential for head injury should begin with the establishment of an airway, ensuring breathing and circulation. The deleterious influence of hypotension (<90 mmHg systolic blood pressure) and hypoxemia (<90% arterial hemoglobin oxygen saturation) on the outcome of patients with severe Traumatic Brain Injury (TBI) was analyzed prospectively on data collected by the Traumatic Coma Data Bank and were among the most profound predictors of outcome.[1]

In accordance with ATLS guidelines, securing of the airway is the initial objective. The TBI patient is unique in that necessity for intubation is not dependent solely upon pulmonary function, but rather the inability to protect the airway secondary to a depressed level of consciousness. Endotracheal intubation is the route of choice as NT intubation may result in further neurological injury in the face of unknown basilar skull fractures. It is also important to note that the nasal-pharyngeal approach should be reserved until after radiographic evaluation for basilar skull fractures. In the setting of the combative patient, intubation is frequently early before further deterioration, as airway protection, oxygen and carbon dioxide exchange is of the utmost importance in the management of the TBI patient. The GCS should be measured after airway, breathing, and circulation are assessed, and after necessary ventilatory or circulatory resuscitation has been performed preferably prior to administering sedative or paralytic drugs.

Hypoxemia should be avoided and immediately corrected upon identification. Patients should be maintained with a respiratory rate to maintain an ETCO2 of 35–40 mmHg, and hyperventilation should be avoided unless the patient exhibits signs of cerebral herniation. Clinical signs of herniation include dilated and unreactive pupils, asymmetric pupils, or a motor exam that identifies extensor posturing.

Venous access with two large bore IVs for volume resuscitation and pharmacological agents is standard of care. The goal of fluid resuscitation is to support oxygen delivery and maximize cerebral
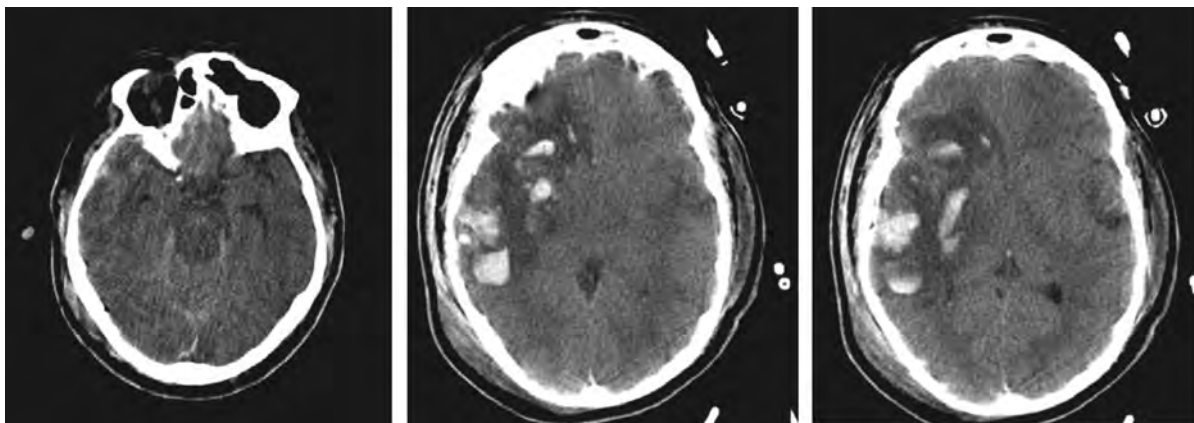

Figure 1 Cranial CT showing a large mixed-density RT temporal hemorrhagic contusion with 8mm midline shift and effacement of basal cisterns.

Table 1 Glasgow Coma Scale.

Response Score	Score
Eye opening	
Opens eyes spontaneously	4
Opens eyes in response to speech	3
Open eyes in response to painful stimulation (eg, endotracheal suctioning)	2
Does not open eyes in response to any stimulation	1
Motor response	
Follows commands	6
Makes localized movement in response to painful stimulation	5
Makes nonpurposeful movement in response to noxious stimulation	4
Flexes upper extremities/extends lower extremities in response to pain	3
Extends all extremities in response to pain	2
Makes no response to noxious stimuli	1
Verbal response	
Is oriented to person, place, and time	5
Conversas, may be confused	4
Replies with inappropriate words	3
Makes incomprehensible sounds	2
Makes no response	1

Figure 2 Pupil anatomy.

intracranial pressure resulting in compression of the parasympathetic fibers running with the third cranial nerve produces a dilated pupil with decreased reactivity. Bilateral fixed and dilated pupils are indicative of brainstem injury or marked elevation of intracranial pressure (ICP). Hypoxemia, hypotension, hypothermia and drugs can also produce dilated pupils reinforcing the fact that it is necessary to resuscitate the patient prior to assessing pupillary function. Although the pupillary examination is an indirect indicator of cerebral function following brain injury, it is useful in immediate decision making and long term prognostics.

Traditionally, TBI is classified by mechanism (closed vs. penetrating), severity (as determined by the Glasgow Coma Scale), and by results of imaging studies.

The Trauma Coma Data Bank divides head injury into three groups based on post resuscitation GCS; mild, moderate and severe head injury.(2) History of TBI, with GCS 15 defines a mild head injury. This group constitutes approximately 80% of all civilian TBI's. A GCS from 9–14 is considered a moderate injury, and GCS of 3–8 is severe, each representing 10%. All patients with a GCS of 8 or less are in coma, defined by the International Coma Data Bank as an inability to interact cognitively with the environment, obey commands, utter words, or open eyes.

Severe head injury patients have the highest incidence of intra-cranial mass lesions, and require intense medical and often surgical intervention. It is also important to note the inverse relationship of systemic injury and GCS. Approximately, twenty five percent of patients GCS ≤8 will have another organ injury.(2)

After the patient is stabilized, and an initial neurological examination is performed, imaging can commence guided by post resuscitation neurological examination and mechanism of injury. Plain skull films have a limited role in TBI and are not used, except in special circumstances. Multi-slice axial CT scans can be rapidly acquired with brain and bone windows and can quickly determine the presence of a surgically correctable intra-cranial lesion and guide therapy. Certain CT findings offer predictive value with regard to outcome: presence/absence of the basal cisterns, midline shift, traumatic subarachnoid hemorrhage, and hemorrhage into the basal cisterns.

Compressed or absent cisterns indicate threefold risk of raised ICP. The basal cisterns are described as open, partially open, or completely obliterated. The presence of midline shift, evaluated at the level of the foramen of Munro, is inversely related to prognosis. Traumatic subarachnoid hemorrhage is the most frequent finding in TBI and occurs in over half of severe TBI patients.(3) Mortality is increased twofold in the presence of traumatic subarachnoid

hemodynamics. Crystalloid is most recommended. If hypotension does occur, it should be promptly restored to minimize secondary brain injury.

Laboratory analysis can often be a rate-limiting step in the rapidly deteriorating TBI patient, so the following tests should be sent after establishing IV access: complete blood count, complete metabolic profile, cross-match for blood, fresh frozen plasma, platelets and coagulation studies, blood gas, and toxicology.

Following the primary survey a focused neurological assessment should be completed. Teasdale and Jennett developed the GCS in 1974 as an objective measure of the level of consciousness in patients with TBI. The patient's initial level of consciousness is both important for the guidance of therapy, and as a prognostic indicator. Age and GCS/Neurological exam are the two most powerful prognostic indicators for outcome in TBI.(1) The GCS is the most widely used measure of defining level of consciousness; it permits reliable reporting and recording of ongoing neurological status by a variety of health-care workers.

The GCS includes the patient's BEST motor, verbal, and eye opening responses. For example, for a patient localizing on the left side and decerebrate posturing (extending) on the right, scores a motor contribution of 5 (M-5) allowing credit for the higher valued motor response of localizing. It is important to take the best exam but to note motor response in all four extremities if present. Stimulation should be presented preferentially to a central point in the unconscious patient. The supraorbital nerve offers central stimulation directly via the trigeminal nerve. It is important to discriminate between withdrawing and localizing. The GCS can be affected by both pre-and post-traumatic factors that may impair neurological response; therefore airway, breathing and circulation should be assessed and stabilized first prior to measuring GCS.

After evaluating the GCS the pupillary exam is important for decision making and prognosticating. It is important to note the size, shape, reactivity, and symmetry. Pupillary asymmetry of less than 1 mm is normal and has no pathological significance.(1) Increased
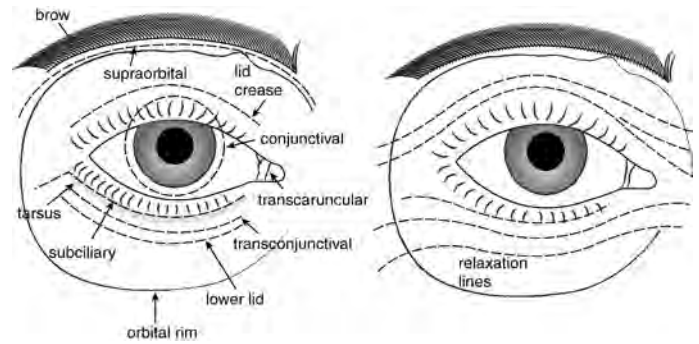
Figure 3.0 Pressure-Volume curve.

Table 2 Classification of head injury

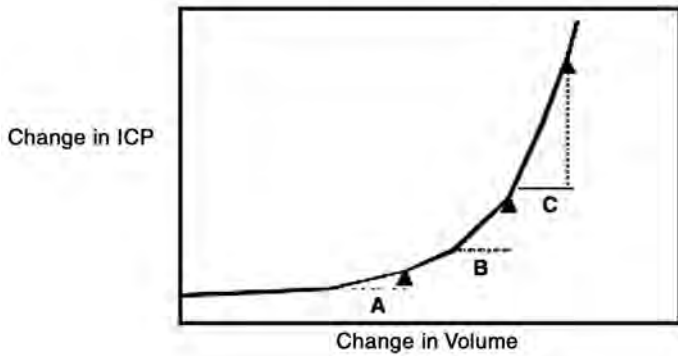| Mild	GCS 15 and history of LOC	80%
Moderate	GCS 9–18	10%
Severe	GCS 3–8	10%

Abbreviation: LOC, loss of consciousness.

Figure 3.1

Figure 3.2 Autoregulation.

hemorrhage.(3) The presence of subarachnoid hemorrhage in the basal cisterns implies an unfavorable outcome of approximately 70%.(3) The clinician must consider that the CT scan is but a snapshot in this dynamically evolving process of "Traumatic Brain Injury." The radiographic findings can sometimes be deceiving as in diffuse axonal injury (DAI). The CT findings in isolated DAI are strikingly disproportionate to the neurological condition of the patient, as is also frequently seen in hypoxic/anoxic injury. Extension of cuts to the cervical spine with sagital and coronal reconstruction adds little time and can help further guide intervention.

At our institution patients with a hemorrhagic but non-surgical lesion found on initial brain CT are routinely scanned again at 4 h post-initial CT scan unless there is rapid deterioration. Approximately 25% of posttraumatic hemorrhages expand in this time. Oertel and colleagues found that 17.5% of patients who had nonoperative lesions on initial CT required surgical intervention based on the follow-up CT scan.(4) Significant factors for the development of delayed ischemic insults include: increasing severity as defined by GCS, the need for cardiopulmonary resuscitation at the accident site, the presence of a subdural hematoma on the first CT, and the presence of a coagulopathy on admission.(4)

WHAT ANATOMICAL AND PHYSIOLOGICAL PROPERTIES MAKE THE BRAIN UNIQUE AFTER INJURY, IN COMPARISON TO OTHER ORGAN SYSTEMS?

The central nervous system contents including the brain, spinal cord, and cerebrospinal fluid are encased in a noncompliant skull and vertebral column. The Monroe–Kellie hypothesis states that the sum of the intracranial volumes of blood, brain, cerebrospinal fluid (CSF), and other components are static and that an increase in one of these or the addition of a lesion (epidural, subdural, or intraparenchymal hematoma) must be offset by an equal decrease in another or intracranial pressure will increase (Figure 3.0). The compensatory mechanism of CSF shifting to the spinal theca and into the venous system via arachnoid granules as well as intracranial blood diverted peripherally is limited. Once these compensatory mechanisms have been exhausted this leads to a linear increase in intracranial pressure (see Figure 3.3, point A). Any increase above and beyond this threshold (point A) will result in an increase in pressure (ICP) with respect to the increase in volume (Figure 3.1).
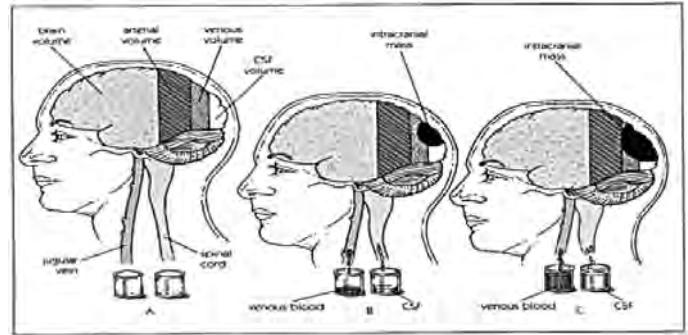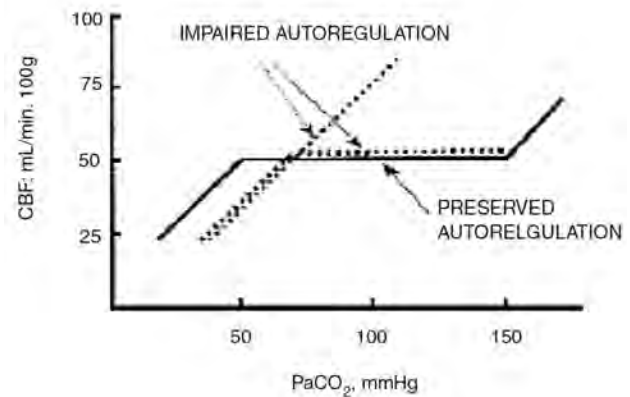
The second unique principle is cerebral autoregulation (see Figure 3.2).

Cerebral autoregulation is the ability of the brain to maintain a constant critical level of cerebral blood flow (CBF) {45–50 ml /100 g/min , 20 ml/100 g/min in white matter to 70 ml/100 g/min in gray matter}over a wide range of mean arterial pressures (MAP) {60–150 mmHg} in a sigmoidal pattern (see Figure 3.2). In the severely injured brain, there is malfunction of autoregulation. The autoregulatory mechanism does not function and the relationship is converted to a linear pattern (see Figure 3.2).

While the exact physiological mechanism is not well understood, studies suggest that the cerebral vascular bed exhibits an intrinsic myogenic regulation of vascular tone, which plays a role. There are several circumstances in which autoregulation is disrupted. Some of the more common etiologies of dysautoregulation include extremes in MAP, traumatic brain injury; severe metabolic disturbances, subarachnoid hemorrhage; severe hypercarbia and/or hypoxemia (see Figure 3.3). The presence of
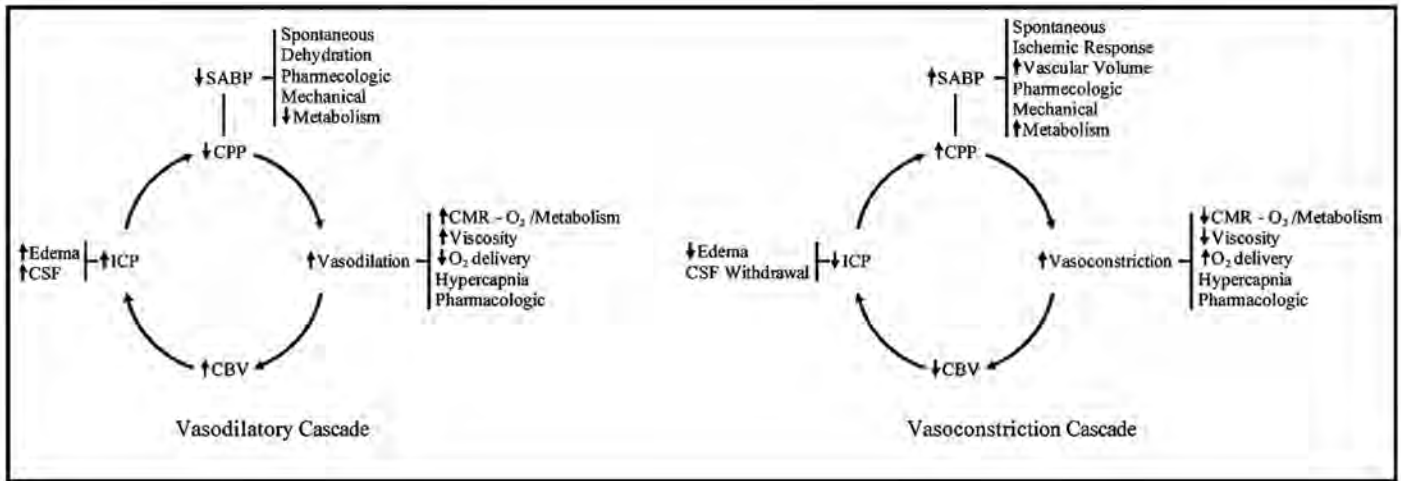
Figure 3.3 The proposed vasodilatory and vasoconstriction cascades model.

dysautoregulation in the TBI patient places extreme burden on the medical staff, as maintaining appropriate MAPs is essential to cerebral blood flow to the injured brain.

As CPP increases, cerebral vasoconstriction limits CBV and ICP. Conversely, a reduction in CPP may stimulate cerebral autoregulatory vasodilation with an increase in CBV and ICP.

HOW DOES THE VOLUME–PRESSURE CURVE IN TBI TRANSLATE TO THE CLINICAL PICTURE?

The curve is a graphical representation of the nature of intracranial elastance, or the change in pressure for a given change in volume (delta P/delta V). The concept of elastance needs to be distinguished from compliance, which is change in volume per unit pressure (think of chest wall/pleura/lung model). In the lung model, we are interested in volume change per unit pressure, whereas in the cranium the change in pressure per unit volume is more relevant. An easy way to visualize these two reciprocal concepts is via a balloon analogy. Compliance relates to how easily a balloon expands when pressure is introduced, whereas elastance refers to the force the balloon exerts against a specific volume when filled. The flat portion of the curve illustrates low-elastance (high compliance), a state where incremental changes in volume are accompanied by relatively small increases in pressure. This low elastance state reflects shunting of CSF and blood to extracranial locations down a developing pressure gradient. The steeper portion of the curve is reached once this shunting mechanism is overcome and small increases in volume lead to large increases in ICP. Clinically, this high-elastance (low compliance) state can rapidly lead to catastrophic cerebral ischemia and herniation if not treated quickly (Figure 3.0).

HOW ARE CEREBRAL BLOOD FLOW AND CEREBRAL PERFUSION PRESSURE MEASURED?

Cerebral blood flow can be measured by direct and indirect means. Direct means of measuring cerebral blood flow include nitrous oxide wash out positron emission tomography, Xenon enhanced CT, Xenon[133] wash out, and thermal diffusion. Additionally, multiple indirect methods are available including single-photon emission computed tomography, MRI, transcranial Doppler, SjVO2, and near-infrared spectroscopy (NIRS). An easy, cost effective repeatable and practical means to repeatedly measure CBF is clinically unavailable. Indirect cerebral perfusion pressure (CPP) measurement provides an estimate of CBF:

$$\text{Cerebral Perfusion Pressure} = \text{Mean Arterial Pressure} - \text{Intracranial Pressure (CPP=MAP–ICP)}$$

WHAT ARE THE PATHOPHYSIOLOGICAL MECHANISMS IN TBI?

Pathophysiologically, traumatic brain injury has been divided into primary and secondary brain injuries. Primary brain injury is a result of immediate mechanical disruption of brain tissue. Primary brain injury is irreversible and the only intervention for primary brain injury is prevention. Some examples of prevention of primary brain injury include: seat belts, helmets, public education, and safety.

Secondary brain injury is the systemic physiological responses to the primary brain injury. The primary underlying pathological mechanism in secondary brain injury after TBI is ischemia. Ischemia is defined as a localized insufficiency of blood flow, delivery of oxygen and nutrients, insufficient for tissue demands.

The consequences of ischemia are first exhibited on a cellular metabolic level, which results in the initiation of a molecular cascade of events (see Figure 3.4). Prolonged ischemia compromises ATP production by disrupting oxidative phosphorylation. This ATP deficit causes immediate malfunction of ATP-dependent ion pumps, leading to increased intracellular sodium and calcium and potassium efflux. Membrane depolarization then occurs, which in turn causes release of excitatory amino acids, and oxygen-free radical formation. This cascade of events leads to cellular necrosis

NEUROMEMBRANE EVENTS IN TBI
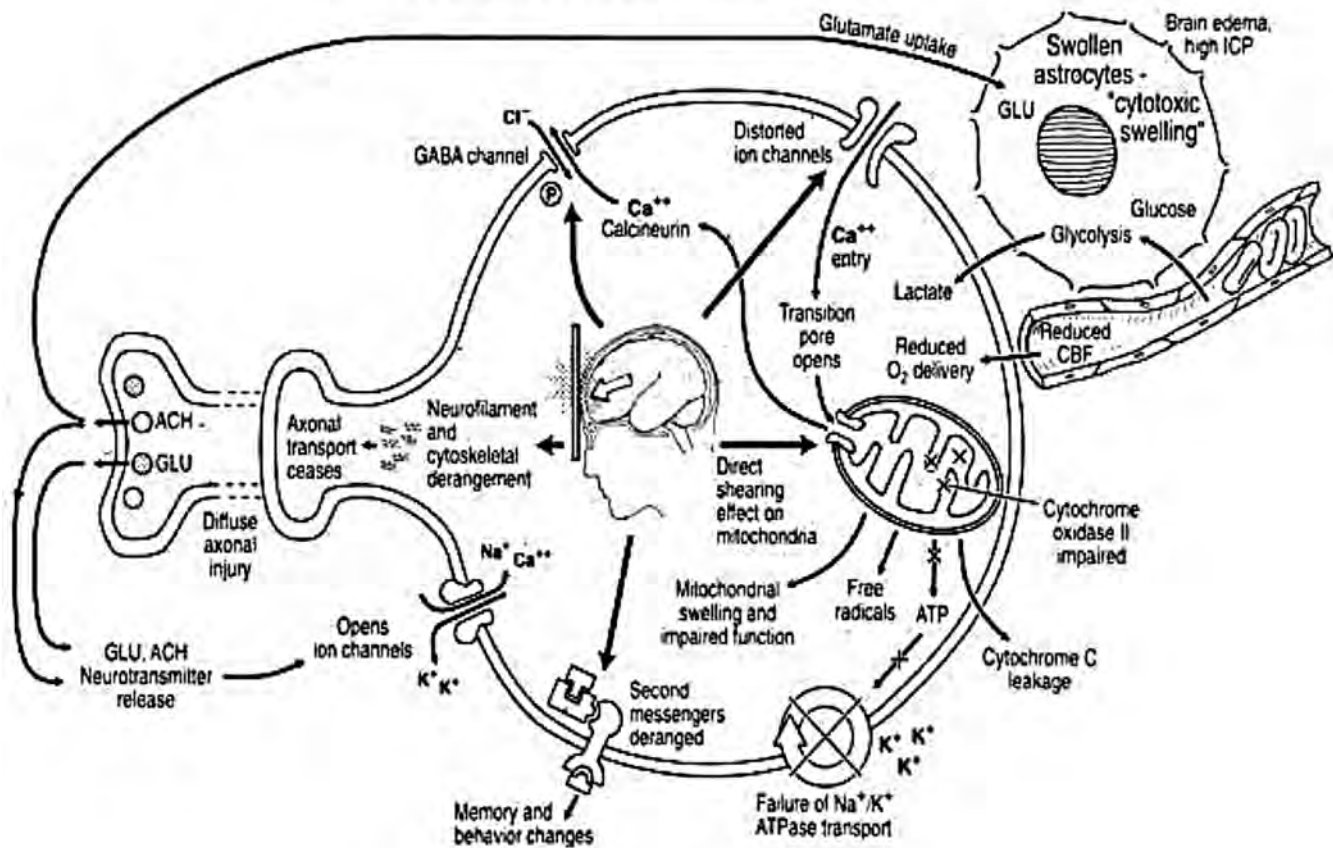
Figure 3.4 Neuromembrane events in TBI (modified from Head injury – Pathophysiology + Management).

and brain edema, which in turn increases ICP further and sets up a catastrophic clinical course if not managed promptly.

WHAT ARE THE TYPES OF INJURY'S ENCOUNTERED IN THE TRAUMA SETTING?

Acute Epidural Hematoma (EDH)

The epidural hematoma is commonly referred to as the "talk and die" hematoma and is the quintessential neurosurgical emergency. A majority of the mortality (10%) and morbidity is secondary to a delayed diagnosis.(5) The peak incidence of EDH is the second decade, with a mean age between 20 and 30; surgical EDHs are rare after the fifth decade.(5) In the patient with suspected and/or documented EDH, it is paramount that this patient's primary survey, trauma work-up and neurosurgical consultation be completed expeditiously. The mechanism of injury is frequently blunt force trauma to the head with an associated temporal bone fracture lacerating the middle meningeal artery 80% of the time. Venous sources of epidural hemorrhage include laceration of the middle meningeal vein or venous sinus. The patient presents with loss of consciousness, and as many as 56% present in coma on admission.(5) A meta-analysis found that 47% of surgical EDH's regained consciousness, becoming lucid, only to succumb to the rapidly expanding hematoma.(5) Untreated patients typically have deterioration in level of consciousness frequently with an

ipsilateral dilated or dilating pupil, observed in 18–44%, and contralateral hemiparesis or hemiplegia.(5) CT is the imaging study of choice for the diagnosis of EDH. It clearly defines the intracranial pathology and allows for identification of additional features that affect outcome, such as underlying intracerebral hematoma. Associated intracranial lesions are found in half of adult patients with surgically evacuated EDH.(5) The associated lesions are predominantly contusion and intracerebral hemorrhages followed by subdural hematoma (SDH) and diffuse brain swelling.(5) An associated SDH or parenchymal hematoma decreases the likelihood of a good outcome.(5)

The Brain Trauma Foundation guidelines strongly recommend that patients with acute EDH GCS <9 with anisocoria undergo evacuation immediately following hemodynamic stabilization. The decision to operate on an acute EDH is based on the patients GCS score, pupillary exam, comorbidities, CT findings (size of the hematoma), and age. Neurological deterioration also influences surgical decision making.

Subdural Hematoma

A subdural hematoma is a hyperdense, crescentic collection between the dura and the brain parenchyma. The mechanisms of injury differ between age groups but MVAs, falls, and assaults account for the majority of SDHs.(6) In patients older than 75–80, falls are the predominate mechanism.(6) An overwhelming
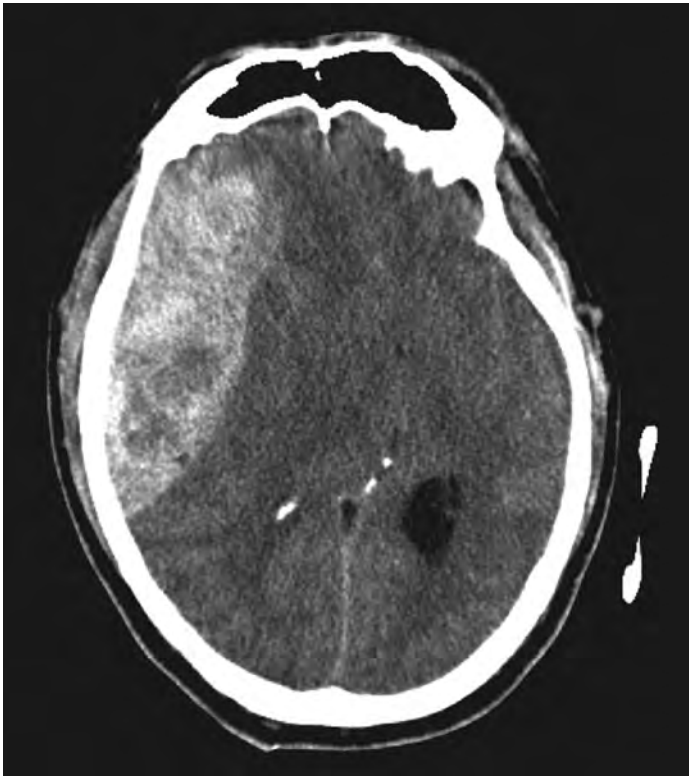
Figure 3.5 Acute right temporal extradural hematoma on CT.

Figure 3.6 Acute left temporal subdural hematoma on CT.

Surgical Indications EDH	Medical Management Option EDH
EDH > 30cc	EDH < 30cc and <15mm thickness and <5 mm MLS
GCS 3–15	GCS >8
+/− Focal Deficit	− focal deficit

Indications for surgery in the SDH Group I	Indications for surgery in the SDH Group II	Indications for surgery in the SDH Group III
>10 mm thick >5 mm MLS GCS 3–15	<10 mm thick <5 mm MLS GCS < 9	Δ Pupils Δ GCS 2 points ICP >20 mmHg

majority (80%) of patients with SDH present with initial GCS scores of eight or less.(6) Pupillary abnormalities are observed in 30–50% of patients on admission.(6) In the majority of cases, the SDH is associated with other intracranial and extracranial injuries.(6) Contusions, intracerebral hematomas, and traumatic subarachnoid hemorrhage are the most frequently associated intracranial injuries.(6) Significant extracranial injuries are observed in 18–51% of patients with facial fractures, extremity fractures, and thoracic and abdominal trauma being the most common.(6) Two main mechanisms have been proposed for SDH. The first is the acceleration/deceleration model wherein the brain is injured by rebounding against the walls of the skull causing a laceration of a cortical vein resulting in a subdural hematoma. The second model is as a consequence of direct transfer of energy from impact resulting in a parenchymal laceration with underlying vessel injury and concominent subdural hematoma.

The decision to operate is based on the GCS score, pupillary exam, CT findings, and general salvageability of the patient.

Increasing age is a strong independent prognostic factor in SDH.(6) Among patients with acute SDH, there is a tendency for older patients (>60) to have a much poorer outcome. Kotwica and Brezezinski found that the mortality for patient's aged 18–30 undergoing surgery was 25% and patients older than 50 years of age, the mortality was 75%.(7) Additionally, Howard et al. found that of 23 patients aged 66 years and older who presented with an acute SDH, 17 died, and the remaining who survived were in a vegetative state or severely disabled.(8) A large 15 × 15 cm craniotomy with evacuation of the clot, and visualisation and coagulation of the bleeding point is required. Timing of surgery has been found to have significant influence on outcomes. Haselsberger et al. studied the time interval from the onset of coma to surgery in 111 patients with acute SDH. Thirty-four were operated on within 2 h after onset, 47% died and 32% recovered with good outcome or moderate disability. In the delayed group of 54 patients who underwent surgery longer than 2 h after the onset the mortality rate was 80% and only 4% had favorable outcome.(9) Dent et al. found that time

to surgery of less than 4 h was associated with a significantly higher rate of functional outcome when compared with surgery delayed for longer than 4 h.(11) However, the mortality was approximately 30% in both groups.(11)

Intracerebral Hematoma (ICH)

Traumatic parenchymal lesions are divided into focal and non-focal lesions. Focal lesions include intracerebral hematomas (ICH), delayed traumatic intracerebral hematomas (DITCH), and contusions. Non-focal lesions consist of edema, hemispheric swelling, and diffuse axonal injury. These lesions often accompany other intracranial mass lesions and their presence has been shown to adversely affect prognosis. Traumatic parenchymal mass lesions occur in up to 82% of all TBI and 80% of severe TBI.(12) The majority of small parenchymal lesions do not require surgical intervention. Larger lesions may place the patient at risk for further neurological deterioration, herniation, and death. Parenchymal lesions tend to evolve especially in the presence of a coagulopathy. Timing of surgery from the onset of neurological deterioration has been shown to greatly affect outcome. Age, GCS score, pupillary response, the presence of hypoxia or hypotension, and the effacement of the basal cisterns of CT scan are the best prognostic indicators in ICH. The location of the lesion, volume, and severity of the surrounding edema affect prognosis.

Skull Fractures

Closed linear skull fractures typically do not require surgical intervention. The presence of a cranial fracture has been shown to be associated with a higher incidence of intracranial lesions, neurological deficits, and poorer outcomes. Macpherson et al. found that 71% of 850 patients with a cranial fracture had an intracranial lesion (i.e., contusion or hematoma), compared with only 46% of 533 patients without a cranial fracture.(13) Hung

Indications for ICP Monitoring
Glasgow Coma Scale score 3–8 after resuscitation
Abnormal admission head CT: hematoma, contusion, edema, herniation, compressed basal cisterns.
Normal admission head CT plus two or more of following: age older than 40, motor posturing, systolic blood pressure less than 90 mmHg.(10)

et al. determined that patients with both loss of consciousness and a cranial fracture were at a significantly greater risk of developing a surgically significant intracranial hematoma.(14)

Depressed cranial fractures complicate up to 6% of TBI in some series.(15) Compound fractures in which the overlying scalp is compromised contaminating the fracture and the galea, account for up to 90% of these injuries.(15) Infection of the central nervous system is substantially increased in this setting and places the patient at great risk of meningitis, cerebral abscess, and cerebritis. Neurological morbidity occurs in approximately 11% of cases, and an incidence of late epilepsy in up to 15%.(15) Conservative treatment may be indicated if open and depressed but not greater than the thickness of the non-displaced segment of bone. Surgical indications include signs of dural penetration, significant intracranial hematomas, frontal sinus injury, gross cosmetic deformity, wound infection, or gross wound contamination. Early elevation and debridement to reduce infection is recommended. All management strategies should include antibiotics therapy.

WHAT ARE CLINICAL INDICATIONS FOR ICP MONITORING?

The BTF have developed management guideline for severe brain injury. Bratton et al. have defined clear guidelines for ICP insertion as the following:

It is important to note that the guidelines are but a blueprint and in no way should supersede clinical experience. *The patient was GCS 4 and a ventriculostomy was inserted, the opening pressure was 26 mmHg.*

WHAT TYPES OF DEVICES ARE AVAILABLE FOR ICP MONITORING?

Many non-medical advances in the technology have translated into great strides in neuromonitoring. Over the decades several intracranial monitoring devices have been developed.

- A. Intraventricular (ventriculostomy) catheter, fluid coupled system
  1. Gold standard for ICP monitoring.
  2. Allows for continuous ICP monitoring, therapeutic/diagnostic CSF drainage.
  3. Risk of infection, tissue damage during placement, hematoma formation.
  4. Placement can be technically challenging, as insertion is a "blind" procedure.

Indications for surgery in the ICH Group I	Indications for surgery in the ICH Group II	Options for CONSERVATIVE management for ICH
Progressive neurological deterioration (attributed to hematoma)	GCS 6–8 with temporal or frontal contusions < 20 cc in volume with >4 mm MLS or compression of basal cisterns on CT	No evidence of neurological compromise
ICP > 20 mmHg refractory to medical management	>50 cc in volume	Controlled ICP
Signs of mass effect on CT scan		No signs of cisternal compression

5. Antibiotic impregnated catheters have significantly lowered the infection risk (1.3% vs. 9.4%.)
- Rifampin and minocycline
- Rifampin and clindamycin

- B. Intraparenchymal monitors
1. Directly measures brain tissue pressure using fiberoptic or strain gauge sensors.
2. Placed in cortical gray matter, risk of tissue damage during placement.
3. Solid-state technology, no tubing to kink or clog
4. Cannot drain CSF, cannot be recalibrated once placed in brain.
5. Acceptable drift that increases each day
6. Used in scenario of diffuse edema where direct ventricular access is difficult secondary to "small or slit-like ventricles"
7. Lower infection rate

- C. Subdural bolt
1. Hollow screw threaded into skull with tip passing into subdural space.
2. No brain penetration may be placed in any location, which avoids venous sinuses.
3. Cannot relieve ICP by draining CSF, infection risk similar to ventriculostomy catheter.
4. Considered obsolete, and inaccurate

- D. Epidural transducer
1. Places pressure-sensitive membrane in contact with dura.
2. Decreased risk of infection since no dural puncture.
3. Cannot therapeutically drain CSF
4. Placement in epidural space difficult, risk of hematoma due to venous plexus.
5. Considered obsolete, and inaccurate

The normal adult ICP adult is 7–15 mmHg. In the TBI patient intracranial pressures <20 mmHg may be tolerated. In most conditions, ICP values of greater than 20–25 mmHg require intervention. CPP is an indirect means to evaluate cerebral perfusion.

CPP = MAP—ICP

The normal range for CPP is 60–90 mmHg. The traditional mainstay of lowering CMRO2 is pharmacological agents. Barbiturates or the combination of a paralytic and sedative are the main methods of decreasing CMRO2. Hypothermia has demonstrated both neuroprotective and CMRO2 reducing benefits and can be used in combination or as a sole agent to lower CMRO2. In order to best optimize CPP, each component of the equation, ICP and MAP, must be considered in both a dependent and an independent fashion. Several scenarios are offered as examples to managing CPP.

Low CPP, normal MAP, high ICP—reduce ICP don't artificially increase MAP

Low CPP, low MAP, normal ICP—increase MAP with pressors

Medical and surgical management of mass lesions and cerebral edema helps to lower ICP and thus increase the CPP. The MAP can be elevated artificially with pressors, however, this can lead to CNS and systemic complications namely ARDS and cardiac events. Current recommendations from the Brain Trauma Foundation (BTF) suggest maintenance of a CPP of 70 mmHg, (16) however, recent articles suggest that CPP be more individually managed and that CPP from 50–70 mmHg may be tolerated.(17)

IS THERE A ROLE FOR HYPERVENTILATION?

CBF varies directly with PaC02 over a range of 20–80 mmHg and for every mmHg change in PaC02; CBF changes 1–2 ml/100 g/min. Hyperventilation is only beneficial for short periods, after 12–24 h of continuous hyperventilation compensatory metabolic mechanisms lead to decreased bicarbonate in the CSF, normalization of pH, and resolution of induced vasoconstriction. Hypercapnia (PaCO² ≥46) and severe hypocapnia (≤30) should always be avoided and prolonged hypoventilation is also contraindicated. BTF guidelines recommend that if severe hypocapnia is necessary, then brain tissue oxygen monitoring (LICOX) should be considered.(18) A safe range for PaCO2 in the TBI patient is 35 mmHg ±2 mmHg.(18) Hyperventilating results in reduced cerebral oxygenation particularly in injured areas, which can exacerbate cerebral hypoxia.(18)

PaCo2 should be maintained at 32 ± 2 mmHg

WHAT IS THE PRIMARY USE OF MANNITOL IN TBI?

Mannitol has been a mainstay of ICP management for over 80 years, yet little evidence exists as to the optimal dosing in TBI. Mannitol is a polycarbonated sugar that acts as an osmotic diuretic, raising the intravascular tonicity and drawing fluid from the extravascular spaces where it is excreted by the kidneys. As a result, intravascular volume is raised and viscosity is reduced allowing for better flow dynamics. The ideal volume state of a severe TBI patient is euvolemic and hypertonic. Mannitol with frequent dosing can result in hypovolemia, so diligence in maintaining euvolemia is important. If utilizing osmotic diuretic therapy sodium and serum osmolality should be monitored frequently. Mannitol 20% (0.25–1 g/kg IV) given over 10–20 minutes can act as a rapid plasma expander by increasing tonicity of blood and help to reduce cerebral edema.(19) It has additional benefits by decreasing the hematocrit and viscosity, and improving CBF and O² delivery. Typically Mannitol takes effect in 15–30 minutes and lasts 1.5–6 h. Burke et al. in 1981 demonstrated the microcirculatory benefits of its rheology properties.(20) Other proposed benefits include scavenging free radicals and reducing CSF production.(21) Renal toxicity has been observed if the serum osmolarity is allowed to exceed 320.

Severe TBI patients are usually was bolused with Mannitol 1 gm/kg and dosed with 0.5 gm/kg, whenever ICP exceeds 20 mmHg

WHAT ARE THE THRESHOLDS AT WHICH A COAGOLOPATHIC PATIENT SHOULD BE CORRECTED AND WHAT ARE THE OPTIONS FOR CORRECTING COAGULOPATHY?

In an aging population the number of individuals taking warfarin for the prevention of thromboembolic complications of atrial fibrillation, cardiac valve replacement, deep venous thrombosis, and thrombophilic states increases. These individuals are at increased risk for intrancranial hemorrhage from trauma or spontaneous causes. A large number of patients with CAD or a history of transient ischemic attacks are also prescribed prophylactic anti-platelet agents. The neurosurgical management of these patients with intracranial bleeds is very difficult, and necessitates urgent reversal of anticoagulation for a rapid surgical intervention. There are no definite values regarding the threshold INR beyond which surgery cannot safely be performed. Yasuda found a high mortality index in patients in the postoperative period in patients with preoperative INR values greater than 1.25. (22) Matheison et al. advocated an INR of 1.2–1.5 for neurosurgical hemostasis (22), and Boulis et al. chose an INR of 1.3 to be the goal of preoperative coumadin reversal.(22)

However, most neurosurgeons require an INR of 1.2 or less. Correction of coagulopathy has traditionally involved the use of FFP, vitamin K, and other blood products. Critical time is wasted while blood products are cross-matched, thawed, and delivered. The volume of FFP required to correct coagulopathy is also problematic exacerbating cerebral edema and in some cases leading to exacerbation of congestive heart failure pulmonary edema, ARDS, and transfusion-related acute lung injury (TRALI).

Activated factor VIIa (rFVIIa) was developed to treat hemophiliacs with high-titer antibodies to factor VIII. rFVIIa initiates thrombin formation by binding with exposed tissue factor. fFVIIa acts in a tissue factor-dependent manner, binding with high affinity to the surface of activated platelets, and enhancing thrombin formation after direct rFVIIa activation of factors IX and X on the surface of the activated platelets. The efficacy has been evaluated in many areas of medicine. Mayer et al. recently studied the effects of three dosing regimes in spontaneous intracerebral hemorrhage (SICH) showing that rVIIa significantly slowed progression of hemorrhage and reduced morbidity and mortality.(23)

Bartal et al. proposed an algorithm to determine the use of rFVIIa in coagulopathic intracranial hemorrhage based on the answer to two principal questions. What is the type of bleeding and what is the risk for expansion of the hematoma? How urgent is the indicated surgery (timing) (24)? Studies have verified that in regards to outcomes, emergent surgical intervention is recommended for EDH or SDH with prominent clinical impairment or progressive deterioration.(5, 6) If not deteriorating conscious patients can be operated on within 24 h.

At our institution, we routinely encounter TBI in patient's anticoagulated with warfarin, and elderly patients on aspirin or clopidogrel with TBI. In a report by Gerotziafas et al. they present two patients with severe thrombocytopenia and life-threatening hemorrhages effectively treated with a single dose of rFVIIa suggesting that there may be a role in treating patients with TBI with effective thrombocytopenia from aspirin or Plavix.(25) They state that the exact mechanism of action is unknown. It has been established that the pivotal step for initiation of coagulation is the FVIIa/ tissue

Table 3 Reversing Anticoagulation in Warfarin-Associated Intracerebral Hemorrage

Management option	Time to anticoagulation reversal	Comments and cautions
Discontinuing warfarin therapy	5–14 d	
Vitamin K	6–24 h to correct INR	Replacement of factors IX and X takes longer than 24 h, risk of anaphylaxis with intravenous injection, warfarin resistance in higher does up to 1 week
Fresh frozen plasma	3–6 h for infusion, typically 12–32 h for reversal	Volume (2–4 L to normalize INR) can be prohibitive
Prothrombin complex concentrate	15 minutes after 10 minutes to 1 h infusion	Limited availability, cost, variable cofactor content based on manufacturer, potentially prothrombotic
Factor VIIa concenrate	15 minutes after bolus infusion	Short half-life, cost, potentially prothrombotic, uncertain safety

factor complex formation. High concentration of FVIIa activate factor IX, which, with cofactor VIIIA, enhance factor X activation and subsequent thrombin generation on the platelet surfaces. Regardless, there exists a possible role for Factor VII in TBI complicated by anti-platelet agents.

> The patient was given four units of FFP, which marginally corrected the PT and was then given Factor VII 100 mcg/kg and taken to the OR.

WHAT ARE THE TBI INDICATIONS FOR ANTI-EPILEPTIC DRUGS (AED)?

The decision to prophylactically begin anticonvulsive therapy is based on the type and location of the brain injury. Subdural, epidural, intracerebral hematomas, and isolated contusions in the frontal, temporal, or parietal lobes should be started on therapy. The temporal and frontal lobes are particularly epileptogenic. DAI and isolated subarachnoid hemorrhage does not

necessitate AED. Temkin et al. found that AEDs were beneficial in preventing early post-traumatic seizures.(26) Phenytoin and valproic acid have long been used as prophylactic therapy in TBI. Okonkwo et al. found that leviteracetam was as effective as phenytoin in preventing early posttraumatic seizures but is associated with an increased seizure tendency on EEG analysis.(26)

> The patient was started on leviteracetam. Keppra is as efficacious as phenytoin in prevention of posttraumatic seizure activity(27) and there is evidence that it may be neuroprotective as well.(28)

INDICATIONS FOR BARBITURATES

Barbiturates enhance and mimic also the action of GABA at the GABA$_A$ receptor complex. Barbiturates also decrease CMRO2 and reduce CBF by directly effecting vasomotor tone as well as free radical scavenger action and lipid peroxidation. The ICP lowering effect of barbiturates is well known especially in the face of intractable ICP's failing all other therapies. Barbiturates for the management of ICP's anecdotally have been considered an "all or nothing" response. Frequently thiopentone is given as a test dose (250 mg) because of it's 10 minutes half-life to determine effects on ICP. If successful then Eisenberg et al. have advocated pentobarbital 10 mg/kg/ over 30 minutes followed by 5 mg/kg/h × 3 h and maintenance at 1 mg/kg/h for 80% burst suppression on EEG.(29) All studies showed that barbiturates controlled ICP when other ICP therapies failed and patients who underwent barbiturate therapy and who did not respond had high mortality and morbidity. Many experts think barbiturates should be reserved for the 15 % of patient who fail all other therapy, as they have been shown to have no benefit when given prophylactically. A Cochrane report found outcome was no different with Barbiturates in severe TBI.(30) Barbiturates are not without substantial systemic side effects; almost every organ system is affected by the use of barbiturates and myocardial depression is often the limiting factor.

WHEN IS IT APPROPRIATE TO DRAIN CSF?

CSF drainage is an efficient and highly effective means to manage ICP. It utilizes the principles of the Monroe–Kellie doctrine to divert CSF to a drainage bag. In addition to intracranial hypertension from edema or mass lesions, hydrocephalus is another diagnosis for which a ventriculostomy may be required, especially in those rare patients with posterior fossa lesions. In the hydrocephalic TBI patient the CSF may be continuously drained or drainage can be based on pressure or volume. The pressure model allows for the height of the drainage bag to correspond to a pressure, once the ICP exceeds this pressure it will drain until the pressure is equilibrated. The volume model requires the height of the drainage system to be manually titrated to gain a constant flow of CSF over one hour, usually <10 cc/h. Drainage of large amounts of

Table 4 Barbiturate side effects.

Organ system	Side effect
Cardiac	Myocardial suppressive with decreased PVR resulting hypotension
Pulmonary	Pulmonary hypertension
Immune	Anergy prevents leukocytosis
Digestive	Gastric stasis
Integument	Hypothermia
	Decubiti (immobility)
CNS	Small sluggish-NR
	Mid-dilated NR pupil at higher doses
	Preserves herniation dilation

CSF carry the risk of expanding an extra-axial collection by "untamponading effect" and reflexive hypotension.

> The height of the drainage system is set at 10 cm above the ear, and a standing order for drainage of 5–10 cc/h for ICP >20 mmHg for 5 sustained minutes, is used.

WHAT ARE THE VARIOUS TYPES OF FLUIDS USED TO RESUSCITATE THE TBI PATIENT?

A wide range of concentrations of saline has been administered in the clinical setting for the TBI patient. Several studies have used ranges from 3 to 23.4% saline in the setting of cerebral edema.(31) As a general principle glucose should be excluded from all solutions whenever possible. Evidence of little benefit exists in support of one concentration over another. Several studies and case reports exist showing longer duration and greater reduction of ICP when comparing hypertonic saline to mannitol.(31) Most centers prefer isotonic crystalloids and use mannitol as needed for ICP control. It is important not to use hypotonic solutions in the TBI patient as this may exacerbate and aggravate cerebral edema.

> The patient was started on NS at 85 cc/hr. After resuscitation it is our goal to maintain patients in a slightly hyperosmolar euvolemic state. We choose to maintain our patients on isotonic crystalloids and use mannitol as needed to control elevated ICPs. We avoid hypotonic fluids as disruption of the blood–brain barrier in traumatic brain injury can lead to exacerbation of cerebral edema when hypotonic fluids and dextrose containing fluids are used.(32) We advocate early enteral feeding via a Dobhoff tube placed post pyloric. Another viable option would be hypertonic saline. Although there is no single best fluid for traumatic brain injury patients, isotonic saline is widely available and can be justified on a scientific basis.(32)

Figure 3.7 Intraoperative photograph to show a large fronto -temporo parietal craniotomy,for evacuation of acute subdural hematoma.

WHAT ARE THE SURGICAL INDICATIONS FOR EXPLORATORY BURR HOLES?

Exploratory burr holes are usually restricted to austere medical environment such as the battlefield or weather-bound communities. Most community hospitals have the advantage of CAT scan, which will eliminate the necessity for blind exploration of the cranium.

Decompressive Craniectomy

Decompressive craniectomy is typically reserved for intractable ICP's failing maximal medical therapy. Historically, decompressive craniectomy has been considered a "salvage" procedure. A direct comparison is difficult because of different endpoints and surgical techniques. A wide range of outcomes has been reported after the procedure. There are currently two studies underway worldwide.

1. The Randomized Evaluation of Surgery with Craniectomy for Uncontrollable Elevation of ICP (RESCUEicp) in Europe. Patients with severe TBI and elevated ICP refractory to medical management without barbiturates are randomized to either decompressive craniectomy or continued medical management including barbiturate coma. Endpoints are the GOS on discharge and GOSE at 6 months.
2. In Australia the DECRA study has the goal to improve indications and standardization of the procedure.

Table 5 Literature Review of Outcomes in Decompressive Craniectomy for severe TBI.

	N	Unfavorable (%)	Favorable (%)
US-Maryland 2006	50	60	40
China 2005	241	60.2	39.8
Turkey	100	84	16
France 2003	40	75	25
US-Hopkins 2003	18	67	33
US-UCLA 2002	24	37.5 (mortality only)	?
Berlin 2002	62	70.9	29.1
UK-Cambridge 2001	26	31	69
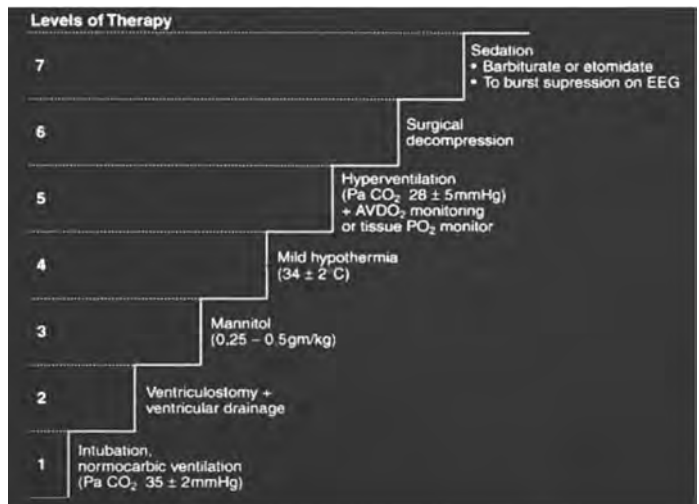
Figure 3.7 "Staircase" algorithm for ICP control in severe TBI.

In collaboration with the Evidence-Based Practice Center (EPC) from Oregon Health and Science University (OHSU) to develop criteria and procedures for the quality assessment of literature, criteria were derived in accordance with those from the US Preventative Services Task Force (33), the National Health Service Centre for Reviews and Dissemination (United Kingdom) (34), and the Cochrane Collaboration.

Levels of recommendation are Level I, II, III, derived from Class I, II, and II evidence. Level I recommendations are based on the strongest evidence for effectiveness and represent principles of patient management that reflect a high degree of clinical certainty. Level II recommendations reflect a moderate degree of clinical certainty. For level III recommendations, the degree of clinical certainty is not established.(35)

CRITERIA FOR CLASSIFICATION OF EVIDENCE

Quality Assessment of Diagnostic Studies

Criteria for grading the literature:
The Brain Trauma Foundation has graded the available literature, to formulate the management guidelines, summarised in table 6 below.

Table 6 Summary table of the guidelines for management of severe closed TBI (modified from the BTF guidelines, 2007).

Topic	Level I	Level II	Level III	ACCP Recommendation*
Blood pressure	Insufficient data	Blood pressure should be monitored and hypotension (SBP < 90 mmHg) avoided	Oxygenation should be monitored and hypoxia (PaO2 < 60 mmHg or O2 saturation < 90%) avoided	Avoid SBP <90 mmHg—1C Keep PaO2 >60 mmHg or SaO2 >90%—2C
Hyperosmolar therapy	Insufficient data	Mannitol is effective for control of raised intracranial pressure (ICP) at does of 0.25 g/kg body weight. Arterial hypotension (SBP < 90 mmHg) should be avoided	Restrict mannitol use prior to ICP monitoring to patients with signs of transtentorial herniation or progressive neurological deterioration no attributable to extracranial causes	Effectiveness in controlling ICPs—1C
Prophylactic hypothermia	Insufficient data	Insufficient data	Pooled data indicate that prophylactic hypothermia is not significantly associated with decreased mortality when compared with normothermic controls. However, preliminary findings suggest that a greater decrease in mortality risk is observed when target temperatures are maintained for more than 48 h	2B–C
Infection prophylaxis	Insufficient data	Periprocedural antibiotics for intubation should be administered to reduce the incidence of pneumonia. However, it does not change length of stay of mortality. Early tracheostomy should be performed to reduce mechanical ventilation days. However it does not alter mortality or the rate of nosocomial pneumonia	Routine ventricular catheter change or prophylactic antibiotic use for ventricular catheter placement is not recommended to reduce infection. Early extubation in qualified patients can be done without increased risk of pneumonia	Periprocedural antibiotics—1B
Deep vein thrombosis prophylaxis	Insufficient data	Insufficient data	Graduated compression stockings or intermittent pneumatic compression stockings are recommended, unless lower extremity injuries prevent their use. Use should be continued until patient is ambulatory. Low molecular weight heparin or low dose unfractionated heparin should be used in combination with mechanical prophylaxis. However, there is an increased risk for expansion of intracranial hematoma.	2C

Topic	Level I	Level II	Level III	ACCP Recommendation *
			There is insufficient evidence to support recommendations regarding the preferred agent, dose, or timing of pharmacologic prophylaxis for DVT	2C
Indications for ICP monitoring	Insufficient data	ICP should be monitored in all salvageable patients with a severe traumatic brain injury (TBI: GCS 3–8 after resuscitation) and an abnormal CT scan. An abnormal CT scan of the head is one that reveals hematomas, contusions, swelling, herniation, or compressed basal cisterns	ICP monitoring is indicated in patients with severe TBI with a normal CT scan if two or more of the following features are noted at admission: age over 40 years, unilateral or bilateral motor posturing, so systolic blood pressure < 90mmHg	1B
Intracranial pressure thresholds	Insufficient data	Treatment should be initiated with ICP thresholds above 20 mmHg	A combination of ICP values, and clinical and brain CT findings should be used to determine the need for treatment	1B
Cerebral perfusion thresholds	Insufficient data	Aggressive attempts to maintain CPP above 70 with fluids and pressors should be avoided because of the risk of adult respiratory distress syndrome (ARDS)	CPP of < 50 should be avoided. The CPP value to target lies within the range of 50–70 mmHg. Patient with intact pressure autoregulation tolerate higher CPP values. Ancillary monitoring of cerebral parameters that include blood flow, oxygenation, or metabolism facilitates CPP management	1B
Brain oxygen monitoring and thresholds	Insufficient data	Insufficient data	Jugular venous saturation (<50%) or brain tissue oxygen tension (<15 mmHg) are treatable thresholds. Jugular venous saturation or brain tissue oxygen monitoring measure cerebral oxygenation	2C
Anesthetics, analgesics, and sedation	Insufficient data	Prophylactic administration of barbiturates to induce burst suppression EEG is not recommended. High-dose barbiturate administration is recommended to control elevated ICP refractory to maximum standard medical and surgical treatment. Hemodynamic stability is essential before and during barbiturate therapy.		1B

Topic	Level I	Level II	Level III	ACCP Recommendation *
			Propofol is recommended for the control of ICP, but no for improvement in mortality or 6 month outcome. High-dose propofol can produce significant morbidity	
Nutrition	Insufficient data	Patients should be fed to attain full caloric replacement by day 7 post-injury		1B
Antiseizure prophylaxis	Insufficient data	Prophylactic use of phenytoin or valproate in not recommended for preventing late posttraumatic seizures (PTS) Anticonvulsants are indicated to decrease the incidence of early PTS (within 7 days of injury). However, early PTS is not associated with worse outcome		1B
Hyperventilation	Insufficient data	Prophylactic hyperventilation (PaCO2 of 25 mmHg or less) is no recommended	Hyperventilation is recommended as a temporizing measure for the reduction of elevated ICP. Hyperventilation should be avoided during the first 24 h after injury when cerebral blood flow (CBF) is often critically reduced. If hyperventilation is used, jugular venous oxygen saturation (SjO2) or brain tissue oxygenation (PbrO2) measurements are recommended to monitor oxygen delivery	1B
Steroids	The use of steroids is not recommended for improving outcome or reducing ICP. In patients with moderate or severe TBI, high-dose methylprednisolone is associated withincreased mortality and is contraindicated			1A

The ACCP conversion of present BTF guidelines cannot be fully satisfied, as the criteria are incompatible in some instances, please refer to source document for clarification.

Class of evidence	Study design	Quality criteria
I	Good quality randomized control trial (RTC)	Adequate random assignment method Allocation concealment Groups similar at baseline Outcome assessors blinded Intention-to-treat analysis Follow up rate of 85% No differential loss to follow up Maintenance of comparable groups
II	Moderate quality RCT	Violation of one or more of the criteria for a good quality RTC
II	Good quality cohort	Blind or independent assessment in a prospective study, or use of reliable date in retrospective study Non-biases selection Follow-up rate of 85% Adequate sample size Statistical analysis of potential confounders
II	Good quality case–control	Accurate ascertainment of cases Non-biased selection of cases/controls with exclusion criteria applied equally to both Adequate response rates Appropriate attention to potential confounding variables
III	Poor quality RTC	Major violation of the criteria for a good or moderate quality RTC
III	Moderate or poor quality cohort	Violation of one or more criteria for a good quality cohort
III	Moderate or poor quality case control	Violation of one or more criteria for a good quality case–control
III	Case series, databases, or registries	

BTF	BTF to ACCP
I	1 A
II	1 B–C
III	2
With A–C levels as indicated	

Class I: Evaluates relevant available screening test; uses a credible reference standard: interprets reference standard independently of screening test: reliability of test assessed; has few or handles indeterminate results in a reasonable manner; includes large numbers (more than 100) broad-spectrum patients with and without disease.

Class II: Evaluates relevant available screening test; uses reasonable although not best standard; interprets reference standard independent of screening test; moderate sample size (50–100 subjects), and with a "medium" spectrum of patients. A study may be Class II with fewer than 50 patients if it meets all of the other criteria for Class II.

Class III: Has fatal flaws such as uses inappropriate reference standard; screening test improperly administered; biased ascertainment of reference standard; very small sample size of very narrow selected spectrum of patients.(35)

In the current ACCP grading system assignment of Grades A to C focuses on the likelihood of bias and is based on the methodological quality of the underlying evidence. RCTs with consistent results are classified as Grade A. Randomized trials with inconsistent results or major methodological weakness are assigned Grade B. Evidence leading to Grade C comes from observational studies and from generalization from randomized trials in one group of patients to a different group. If experts are very certain that benefits do, or do not, outweigh the risks, they will make a strong recommendation, Grade I. If they are less certain of the magnitude of the risks and benefits, they make a weaker Grade II recommendation.(36) A direct conversion from BTF to ACCP grading is difficult. For the benefit of those involved we have attempted to convert BTF recommendation into ACCP grading system. This is an imperfect conversion, and we would strongly encourage the reader to refer to the original grading system.

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4   Minor blunt head injury in the intoxicated patient
Eleanor S Winston and Lisa Patterson

A 21-year-old man at a party trips over a table when getting up for another beer. He is initially unconscious and is noted to have a forehead laceration. His friends call Emergency Medical Services (EMS) when he doesn't immediately respond to their attempts to rouse him. By the time the ambulance arrives, 4 minutes after the call, the man is struggling to get up and is mildly combative. He is brought on a long board and with a cervical collar to the local hospital's emergency department. On arrival, he smells of alcohol and admits to "my usual" when asked. He is oriented to self, month, year, but not date. He is able to say he is at a hospital but is not sure which one and names a nearby city. His respiratory and hemodynamic parameters are normal. On secondary survey, he has a laceration, beginning in the mid-right frontal region and extending into the hairline. The laceration is oozing, 5-cm long, and extends to the galea with exposed bone. The sclerae are injected, the pupils are equal and reactive, and extraocular movements are normal and symmetric. The oropharynx and the nasopharynx are normal, and there is no hemotympanum. The patient's neck is not tender, and his torso, extremities, and motor and sensory functions are unremarkable. On reassessing his mental status, the patient is oriented to self, place, and time. He is still amnestic to events surrounding the fall and is repetitively asking "how did I get here?" He relates no significant past medical history, medications, or allergies. He denies smoking or illicit drugs but admits to alcohol on the weekends – "about a 12-pack beer." Family history is unremarkable.

A CT scan of the head (Figure 4.1) reveals a small right frontal subdural hematoma and no bony fracture. The laceration is repaired, and the patient is admitted for serial neurologic examinations. His Glasgow Coma Scale (GCS) remains 15 throughout, but he had one episode of vomiting early after admission. His nausea has since resolved as he is tolerating his breakfast well. He undergoes a structured evaluation of his drinking habits and a brief intervention regarding this alcohol-related trauma. Neurosurgical consultation recommends no need for surgical intervention or further evaluation. He is discharged to home. One week later, he returns to the Trauma Office for suture removal with complaints of headache, dizziness, and difficulty concentrating, focusing, and remembering details in classes. He is reassured that the prognosis for patients with mild traumatic brain injury is good and that most symptoms resolve over a few weeks. A follow-up visit 4 weeks after the incident reveals resolution of the headaches and dizziness. The patient has been able to keep up in his college course work, and short- and long-term memory is "at baseline" in his estimation.
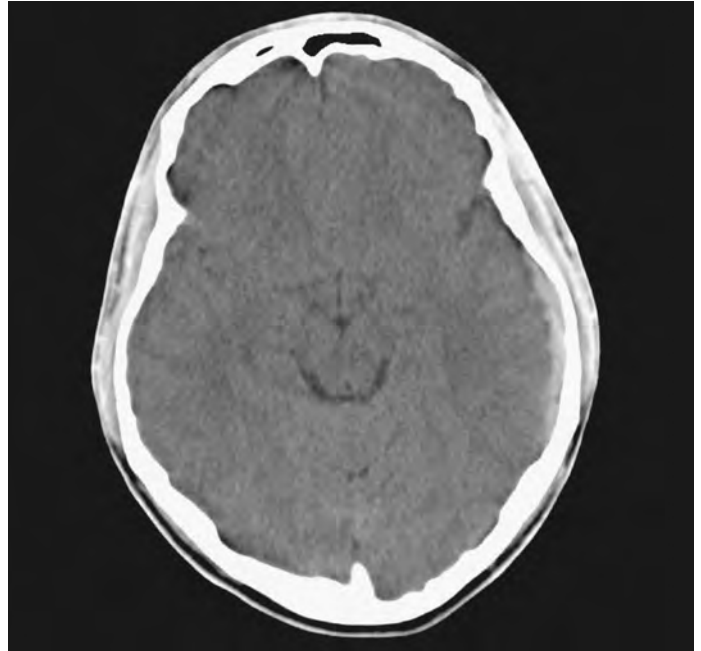
Figure 4.1 CT scan of the head reveals small left subdural hematoma.

MINOR TRAUMATIC BRAIN INJURY: OVERVIEW

Definition of Minor Traumatic Brain Injury
Although authors of studies, literature reviews, and guidelines have defined minor traumatic brain injury (MTBI) in various ways, the definition provided by the WHO Collaborating Center of Neurotrauma Task Force on Mild Traumatic Brain Injury is most commonly used. This definition states that

MTBI is an acute brain injury resulting from mechanical energy to the head from external physical forces. Operational criteria for clinical identification include: (i) 1 or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, post-traumatic amnesia for less than 24 h, and/or other transient neurological abnormalities such as focal signs, seizure, and intracranial lesion not requiring surgery; (ii) Glasgow Coma Scale score of 13–15 after 30 minutes post-injury or later upon presentation for healthcare. These manifestations of MTBI must not be due to drugs, alcohol, medication, caused by other injuries or treatment for other injuries (e.g., systemic injuries, facial injuries or intubation), caused by other problems (e.g., psychological trauma, language barrier or coexisting medical conditions) or caused by penetrating craniocerebral injury.(1)

This definition expresses the understanding that MTBI encompasses a broad range of injuries from the barely perceptible on clinical exam with no change seen on imaging studies to significant neurologic changes and obvious injury seen on scanning.

Epidemiology of MTBI
The majority (70–90%) of patients with brain trauma have MTBI. (2) The overall incidence of this condition ranges 100–300/100,000,

although higher rates (600/100,000) were reported when patients were asked to report episodes of trauma-related loss of consciousness or alterations in mental status. Thus, it seems that MTBI is underestimated by only counting those who present to hospital or are admitted for treatment.(2) Indeed, in a recent paper querying veterans returning from Iraq, nearly 15% of respondents were found to have had an injury with loss of consciousness or brief alteration in mental status.(3)

Men have 1.4–2 times the risk of MTBI than women, with adolescents and young adults at the highest risk. Motor vehicle collisions and falls are the main causes of MTBI. Sports-related incidents are also common in certain age groups and in certain sports though the true incidence is again difficult to determine given the lack of data.

Evaluation of the Patient with MTBI and Alcohol Intoxication

Nearly half (37–51%) of all patients presenting with traumatic brain injury (TBI) are intoxicated at the time of injury.(4) For those patients with altered mental status who admit to alcohol intake or who smell of alcohol, simply attributing the change in mental status to alcohol intoxication without further evaluation is risky.

The Effect of Alcohol on Mental Status/GCS

A recent literature review revealed that despite the trend in intoxicated patients toward more severe TBI, longer hospital stay, and increased likelihood of intubation and treatment, no significant effect is seen on their post-injury GCS.(4) The mean GCS score of nonintoxicated and intoxicated patients stratified by AIS in a registry review did not vary by more than 1 GCS point in any of the severity classes—concussion, AIS3, and AIS4. In AIS 5 patients, the variance between intoxicated and nonintoxicated patients was significant at 1.5 and 1.4 points, which is not clinically significant.(5) A NTDB-derived study in patients positive and negative for blood alcohol and stratified by AIS indicated that the presence of alcohol did not lower the GCS by more than 1 point in any head AIS group. This study suggests that evaluation and intervention should be accomplished as per GCS without "adjustment" for alcohol level to avoid delaying diagnostic or therapeutic interventions.(6)

The Effect of Alcohol on TBI

A review of studies evaluating the effect of alcohol use and abuse on TBI and its sequelae found that 23–51% of all evaluated patients had blood alcohol level (BAL) > 100 mg/dl. The incidence of pre-injury history of alcohol and of other substance abuse was 18–40% and 10–44%, respectively. A significant number of patients continued to misuse substances post-injury. No conclusion could be drawn regarding the influence of alcohol or other substance misuse on the outcomes of patients with TBI, although a trend toward greater severity of brain injury was noticed in affected patients.(4) In contrast, another retrospective registry review revealed that low alcohol level after trauma is associated with reduced mortality as compared to patients with no alcohol. Nevertheless, in TBI patients, high alcohol level was associated

with increased mortality. It was proposed that alcohol may have neuroprotective effects at lower doses that may be overshadowed by its hemodynamic and physiologic effects at high doses. (7) While the reported prevalence of injury seen on head CT in alcohol intoxicated patients is 8.4% (8), no clinical parameters or neurologic scores that could predict such injuries were identified. In this population, only 1.9% of patients required neurosurgical intervention.(8)

Risk of Evolution of Injury—Is CT Scan Mandatory for All?

Given the frequency of MTBI, the evaluation by CT or hospital admission of all patients regardless of their symptoms and history is prohibitively expensive and may expose many patients to unnecessary radiation. On the other hand, missing a potentially treatable injury is equally unacceptable. Thus, many investigators have tried to elucidate the mechanism of injury, degree of mental status changes or loss of consciousness, concomitant injuries, or other factors that can winnow out those patients whose injuries will not evolve to require a neurosurgical intervention. In addition to this challenge, much research focused on identifying those MTBI patients who do need a head CT. This issue has specific implications for those individuals who live in resource-depleted regions where a decision to obtain a head CT means transfer to a distant hospital.

Several studies established that the prevalence of CT scan abnormalities as well as the need for surgical intervention in MTBI patients is reversely proportional to the GCS.(9–12) These investigations reported 5–8% incidence of abnormal CT findings in patients with GCS 15, approximately 20% in those with GCS 14, and more than 30% in those with GCS 13. The rate of surgical intervention rises from 0.08–0.4% in patients with GCS 15–7.5% in patients with GCS 13, while the overall rate for patients with GCS 13–15 is 1–1.5%.(9–12)

Some investigators recommend that all patients with MTBI undergo CT scanning and that admission be reserved for those with clinically significant CT findings or with neurologic abnormalities.(13) Others advocate a more selective approach. For example, Palchak, in a prospective evaluation of 2,043 children <18, suggested that CT scan is not mandatory. Isolated loss of consciousness (LOC) or amnesia in the absence of other clinical findings suggestive of TBI (seizure, vomiting, headache, dizziness, nausea, vision change, abnormal mental status, focal neurologic deficit, skull fracture, or scalp trauma) did not predict TBI on CT or TBI requiring acute intervention.(14) Similar findings are reported in adult patients, suggesting that observation alone can be appropriate in selected patients.(15)

Clearly, only a minority of patients presenting with MTBI are at risk for the need of emergent intervention. The difficulty lies in finding these patients in the much larger group of patients with MTBI.(16–19) Only a few may be discharged with observation. Two externally validated decision rules have been developed, and a third is awaiting external validation. These outline criteria that predict findings on head CT and need for surgical intervention in patients presenting with MTBI.(11, 12, 20–22) The WHO Task force on MTBI has developed an evidence-based algorithm based, in part, on the above. They recommend that patients be discharged home with observation—who have GCS 15 and who

do not have any of the following criteria: age ≥60 years, vomiting, headache, seizure, anterograde amnesia, dangerous mechanism (pedestrian struck by a motor vehicle, occupant ejected from a motor vehicle, fall from height >3 ft or 5 stairs), GCS 13 or 14 on arrival, drug or alcohol intoxication, and skull fracture (suspected open or depressed, signs of basal skull fracture).(9)

> In the presented case, indications for head CT include intoxication and amnesia.

Observation

Patients with GCS 15 and normal CT scan do not need admission for neurologic observation and can be discharged home from the ED with a caregiver.(13, 18, 19, 23–27) Recommendations for discharge criteria include normalization of the GCS/mental status as well as resolution of nausea/vomiting and balance issues. Where access to CT is not readily available, admission for observation is an alternative. No specific length of observation has been set forth or studied, most series implying discharge when symptoms resolve.(19, 28) The evaluation of the trauma patient who may have other injuries will frequently span 3–5 h and afford the chance to closely observe the patient for deteriorating mental status.(15) The WHO task force recommends 24 h observation minimum, to be adjusted by clinical factors. The average length of stay for observation after MTBI is 1.4 days. Economic modeling showed CT scan to be more cost effective than admission for observation. (29) In contrast, admission for observation is recommended for patients over 70 years and for those taking anticoagulants, as their risk for worsening CT findings is higher.(30, 31)

> Discharge is not advisable; given the findings on head CT, admission for observation is warranted.

Repeat Head CT

Admitted MTBI patients with increased risk for worsening of brain injury should have a repeat head CT. Several risk factors have been identified including abnormal initial head CT, especially when multiple traumatic lesions are present, age >65 years, GCS <15 (13 or 14), shorter interval to first head CT (<90 min), and anticoagulation.(31–33)

Routine repeat head CT is not helpful in patients with MTBI, as it results in extremely small rates of intervention in both adult (33–36) and pediatric patients.(37) Furthermore, normal neurologic examination at the time of the repeat cranial CT predicts in 100% the lack of need for neurosurgical intervention or change in management. (38) Thus, repeat head CT is not useful for patients with normal initial head CT who do not manifest neurologic deterioration.

> Our patient's mental status has resolved over his hospital course; a routine repeat head CT has low yield, is not cost effective, and is not indicated in the absence of deterioration in the clinical exam.

MANAGEMENT CONCERNS

Anticonvulsants

The Brain Trauma Foundation iterates the following risk factors for developing posttraumatic seizures: GCS <10, cortical contusion, depressed skull fracture, subdural hematoma, epidural hematoma, intracerebral hematoma, penetrating head wound, and seizure within 24 h of injury.(39) As patients with MTBI may have some of these risk factors, they are at higher risk for developing both early and late onset seizures. There are no specific recommendations for anticonvulsant therapy in MTBI patients, and guidelines can only be inferred from the global Level II recommendations set forth by the Brain Trauma Foundation. These guidelines suggest that prophylactic anticonvulsant therapy is indicated to decrease the incidence of early posttraumatic seizures and is not recommended for preventing late posttraumatic seizures.(39)

Correction of Coagulopathy

Although the notion that morbidity and mortality from TBI are increased in anticoagulated patients has long been held, the effect of anticoagulation on these parameters has been quantified only recently. A retrospective review of 380 TBI patients with pre-injury anticoagulation demonstrated a four- to five-fold higher risk of death compared with controls.(40) Furthermore, analysis from two large trauma databases demonstrated 84% and 71% mortality, respectively, in coagulopathic (mean INR 4.6) patients with MTBI.(30) Likewise, patients taking antiplatelet medication also had a threefold higher risk of death.(41)

The detrimental effect of anticoagulation on outcome of patients with TBI mandates early recognition and aggressive reversal of the coagulopathy. Indeed, protocols for rapidly identifying patients on anticoagulants and antiplatelet medications with provisions for rapid correction were developed. In patients with coagulopathy and TBI requiring surgical intervention, low-dose administration of FVIIa rapidly reversed the coagulopathy when administered alone and in conjunction with fresh frozen plasma (FFP), vitamin K.(42, 43) The time to intervention and overall volume of FFP required to correct the coagulopathy were decreased. No study to date has investigated FVIIa for correction of coagulopathy in patients with MTBI and normal head CT, who are at risk for delayed bleed. FVIIa corrects coagulopathy rapidly, but it carries risk of thrombosis. The risk benefit ratio may not be favorable for some patients. Interestingly, empiric administration of FFP in severely brain-injured patients did not lead to improved mortality; on the contrary, mortality was significantly greater as was increased frequency of delayed traumatic intracranial hemorrhage.(44)

Postconcussive Disorder

Postconcussive disorder manifests as a wide complex of neurological, emotional, psychiatric, and cognitive symptoms that last beyond the expected period of recovery. Specifically, this condition is defined by onset within 4 weeks of loss of consciousness and symptoms in at least three of the following categories: (1) headache, dizziness, fatigue, and noise intolerance; (2) irritability, depression, anxiety, and emotional lability; (3) subjective concentration, memory, or intellectual difficulties without neuropsychological evidence of marked impairment; (4) insomnia; (5) reduced alcohol tolerance; and (6) preoccupation with above symptoms and fear of brain damage, with hypochondriacal concern and adoption of sick role.

The severity and duration of postconcussive symptoms (PCS) depends on the population studied. For example, young children and sports players exhibit a lower rate and shorter duration of posttraumatic manifestations compared with litigants. Interestingly, patients without head injury who are afflicted with posttraumatic stress disorder or depression are found to suffer from similar symptoms and test positively on the same measures as those with MTBI.(3, 45, 46) It is frequently difficult to determine if symptoms are attributable to the brain injury, to preexisting psychiatric or social stressors, or to secondary gain.

In patients with MTBI evaluated postdischarge, nearly 85% exhibited at least one symptom 1 week after injury. At 2 weeks, only 57% were symptomatic. Nearly all symptoms were resolving at 4 weeks with the exception of dizziness still present in 18%. By 8 weeks, 94% had resolution of all PCS. Physical symptoms were rated more adverse by patients early after injury, and emotional disturbance was more adverse at later stages.(47) Physical symptoms and objective measures of cognitive impairment are generally not found late after MTBI and for the most part are resolved by 3 months to 1 year post-injury. Education and reassurance as to the expected course after MTBI can be helpful in guiding patients through recovery and avoiding adverse outcomes.

SUMMARY

Mild TBI is common in blunt trauma patients. While most patients fully recover, a few, mainly the elderly and the coagulopathic, have prolonged symptoms or complicated courses. Selection of patients for evaluation and observation as well as preemptive education of those with post-TBI cognitive and physical symptoms is critical to optimal care and returning the patient to a productive life.

Level of Evidence

Is CT Mandatory for All Patients with MTBI?

A strong recommendation (Grade of recommendation: IB) can be made based on a preponderance of data from the literature, including validated decision rules that clinical criteria obtained from the history and physical exam can be used to select patients at specific risk for intracranial injury, CT findings, and who will go on to require surgical intervention. These patients would best be evaluated using CT. If CT is unavailable, consideration for admission or transfer would be recommended (IC).

Should Patients Be Admitted for Observation?

It is strongly recommended that patients with GCS <15 as well as patients over the age of 70 and patients with coagulopathy be admitted to the hospital for observation (IC). These patients are at significantly higher risk of deterioration despite minimal symptoms on presentation. The length of observation has not been definitively determined and ranges from 3–5 to 48 h.

Is Routine Repeat Head CT Mandatory?

Once injury is identified with CT, in the absence of worsening neurologic examination, routine repeat head CT is not indicated (IA). This is supported by the preponderance of data and subjects the patient to an additional exposure to radiation.

Should Coagulopathy Be Corrected?

Rapid correction of coagulopathy is felt to be the best way to counteract the increased risk patients with coagulopathy have for deterioration and death after MTBI (IB).

Data suggest that FFP, cryoprecipitate, and platelets have been utilized successfully, with some difficulties related to length of time to correction and fluid overload (IB). More recently, early studies have indicated factor VIIa may be used to correct coagulopathy, but it carries a risk of unintended thrombosis for some patients (those with preexisting arterial disease or cardiac stents among them) (2B).

Should Prophylaxis Be Given for Seizure Risk?

Dilantin can be utilized to prevent seizures in the short term (2A).

Postconcussive Syndrome

No specific recommendations regarding postconcussive syndrome can be made. The existing studies do not allow for ready comparison between symptoms related to brain injury and those which arise from other injuries, pain, depression, or other underlying problems.

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5 Stab wound to the carotid artery
Jonathan B Lundy and Stephen M Cohn

A 28-year-old female is brought into the emergency center after sustaining a stab wound to the right side of her neck approximately 15 minutes prior to admission. The paramedic reports finding the patient lying in a large pool of blood; however, bleeding has decreased significantly after direct pressure was applied over the stab wound. She is in respiratory distress with a heart rate of 120 beats/min and a systolic blood pressure of 80 mm Hg. She is combative with no focal deficit. The patient is immediately intubated and becomes profoundly hypotensive after induction. Removal of the dressing reveals a non-pulsatile neck hematoma with a penetrating wound at the level of the cricoid cartilage, 1 cm in length, anterior to the medial border of her right sternocleidomastoid muscle. There is no active bleeding, palpable thrill, audible bruit, or subcutaneous air. A chest X-ray demonstrates no pneumothorax or hemothorax, and the patient is taken to the operating room for neck exploration. An incision is made along the anterior boarder of the sternocleidomastoid muscle from the mastoid process to the suprasternal notch. A large hematoma is identified around the stab wound area. The carotid sheath is identified in a virgin area, and proximal control of the common carotid artery is obtained. Further dissection into the hematoma reveals a 0.5 cm laceration in the anterior wall of the common carotid artery, which is repaired primarily. The exploration is completed with no other injuries identified. The patient is brought to the surgical intensive care unit (SICU) and kept intubated for 2 days because of her neck hematoma and swelling. Fifty hours after surgery, she is successfully extubated. The patient has no neurological deficits and is phonating well.

DEMOGRAPHICS

Carotid arterial injuries account for 0.2% of all trauma-related admissions and make up 5% of all arterial injuries.(1, 2) Penetrating trauma is the most common cause of carotid injury, with gunshot wounds accounting for approximately 50% of these injuries.(3, 4) The incidence of cervical arterial injury in the setting of penetrating neck wounds is noted to be as high as 36% in some series.(5)

DIAGNOSIS

Physical Examination

Physical examination of the patient suffering a penetrating wound to the neck includes ensuring the patient's airway is secure and determining if definitive signs of a cervical vascular injury such as active hemorrhage, palpable thrill, audible bruit, expanding hematoma, or a neurologic deficit are present. The location of the injury in relation to neck structures can guide initial diagnostic and therapeutic maneuvers. Monson and colleagues originally divided the anterior neck into three zones.(6) Figure 5.1 is from the original article by Monson and colleagues and defines the zones of the anterior neck. In Monson's original classification, injuries in zone II are located between the head of the clavicles and the angle of the mandible. Zone I represents an injury below the clavicular head, and zone III penetration is above the angle of the mandible.

Early data indicated that 32% of patients with vascular injuries from penetrating neck trauma have no evidence of vascular damage on physical exam.(7) However, more recent studies refuted this observation. For example, a retrospective review of 110 patients with penetrating injuries to zone II of the neck demonstrated no vascular injuries in patients with a normal physical
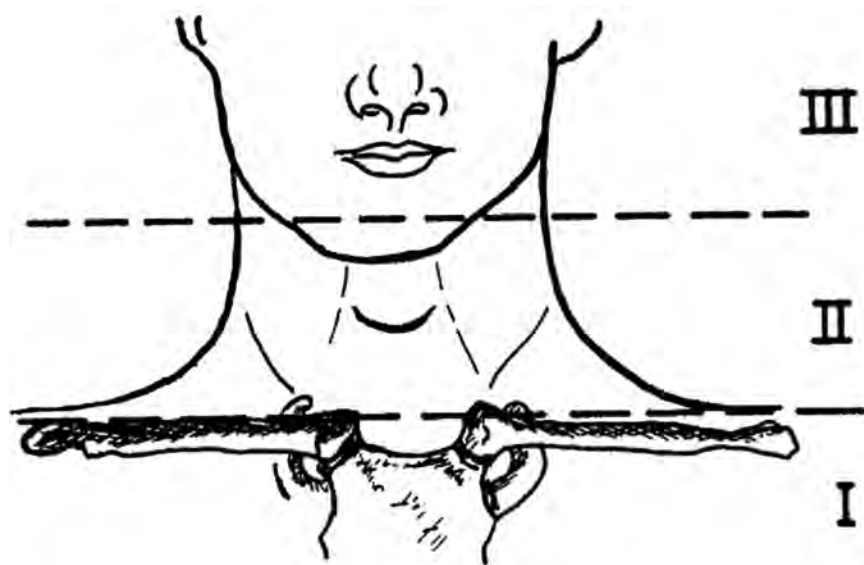

Figure 5.1 Zones of the anterior neck.

(*Source:* Monson DO.(6))

examination.(8) Although nine patients had minor arterial injuries, only one (0.9%) had a major vascular injury requiring operative management that was not predicted by physical exam. A later prospective study in 28 patients with zone II penetrating trauma and no physical finding suggestive of vascular injury also supported the accuracy of physical exam in diagnosing such injuries. (9) In this study, no patient had a vascular injury, as determined by carotid ultrasound. Extension of the same study to 114 patients with no hard signs of vascular injury reported that only one patient required intervention and that 91 patients were observed with no imaging or operative intervention successfully.

Gunshot wounds may be more problematic when physical examination alone is used to screen patients for vascular injuries. A prospective study of 59 stable patients with gunshot wounds to all neck zones demonstrated that physical exam has a sensitivity and negative predictive value of only 57% and 67%, respectively.(10)

Conclusion
Physical examination alone in stable, asymptomatic patients with a penetrating injury to the neck is safe for the detection of a vascular injury. When deciding upon screening tests in this setting, surgeons must take into consideration a higher false-negative rate for gunshot wounds. They should also consider the high efficacy and speed of CTA in diagnosing vascular neck injury (29) (Grade of recommendation: 2A)

Angiography
In the setting of a hemodynamically stable patient sustaining a stab wound in one of the anterior zones of the neck, management can be focused on initial nonoperative therapy with evaluation for injuries to vascular and aerodigestive structures. The diagnosis of vascular injury in penetrating neck trauma in 36% of patients confirms that some form of screening examination should be performed.(5) Although some authors report physical examination has a sensitivity as low as 61% in this setting, others conclude that unlike blunt carotid injury, penetrating trauma to the extracranial carotid artery rarely presents without obvious signs of injury.(11–13) Angiography remains the gold standard for evaluation of extracranial circulation in the setting of penetrating neck trauma without obvious signs of a vascular injury. The controversy regarding mandatory and selective exploration of zone II penetrating injuries is discussed below. In zone I and III wounds, however, some authors recommend imaging due to the difficulty of direct physical examination in these areas, the need to develop an operative plan if an injury is present, and the significant morbidity and mortality associated with a delayed diagnosis of vascular injury. Benefits of angiography include the ability to intervene on vascular injuries such as embolization of active bleeding, temporary balloon occlusion to evaluate for neurologic deterioration, and endovascular stent placement.(14) Complications related to angiography include anaphylactic reaction to iodinated contrast agents, hematoma, thrombosis, aortic dissection, a false-positive study, and most concerning , a false-negative study.(15–19) The false-positive rate with angiography was 14 patients in a series of 183 extremity penetrating injuries.(19)More concerning is a false-negative study, which occurred in 1 of 177 patients in this study. It is interesting to note that the two false-negative studies in a series of 18 penetrating wounds to the thoracic aorta and brachiocephalic vessels occurred in patients with stab wounds (20) Other disadvantages of angiography include the invasive nature of the procedure and time.consumption. Ultimately, aggressive angiographic screening of neck trauma results in negative studies in up to 92% of stab wounds to the neck and 73% of gunshot wounds to the neck.(21)

Conclusion
Angiography in the setting of penetrating neck wounds without hard signs of vascular injury may be utilized on a case-by-case basis. Given the high rate of negative studies, the low likelihood of a negative physical examination in the setting of penetrating cervical vascular injuries, and the availability of less invasive imaging techniques, angiography is not mandatory. There may be benefit in the setting of injuries to neck zones that are difficult to expose operatively, such as zones I and III (Grade of recommendation: 2A).

Computed Tomographic Angiography (CTA)
Due to the high rate of negative angiographic studies in penetrating neck trauma, multiple centers have evaluated the use of less invasive imaging methods. Computed tomography is used around the clock in most hospitals around the country, and in trauma centers, these devices are typically located near the emergency center. CT has the added advantages of consumption of less resources, has less cost than conventional angiography, does not have arterial vascular complications associated with its use, identifies associated injuries or lesions to neck structures in neck trauma in 34.9% of patients, and can demonstrate trajectory in deep soft tissues of the neck, assisting with exclusion of vascular injuries.(22–24) The application of CT technology to evaluate vascular pathology has been extensively studied.(14) CT angiography (CTA) of the neck has been most frequently evaluated in the diagnosis of atherosclerotic occlusive disease. Soto and colleagues performed CTA for suspected arterial extremity injuries in 45 consecutive patients.(25) Findings included 19 vascular injuries and 24 normal studies. Separate sensitivities and specificities for the two interpreting radiologists evaluating CTA were 90/100% and 100/100%. Munera and colleagues prospectively evauated CTA for penetrating neck trauma in 60 patients. (14) CTA identified 9 of 10 vascular injuries identified by conventional angiography. The only false-negative CTA was a study that did not include the lower neck in the region evaluated in a patient with an angiographically identified pseudoaneurysm at the origin of the common carotid artery. In Munera's study, the sensitivity and specificity of helical CTA for penetrating neck trauma were 90% and 100%, respectively. Munera and colleagues went on to use CTA alone in the prospective evaluation of 175 consecutive penetrating neck trauma patients.(22) A total of 173 CTA were deemed adequate for interpretation. Two studies demonstrated significant artifact and underwent conventional angiography with normal findings. A total of 27 patients with 28 cervical vascular injuries were identified. A total of 9 patients were lost to follow-up, and no patient developed delayed signs

or symptoms of arterial injury during the 6-month follow-up. More advanced CT technology such as multi-detector row array image acquisition has proven useful in cervical vascular trauma. Berne and colleagues reported their experience with 16-slice multi-detector CTA to evaluate for blunt cerebrovascular injuries in 435 patients(26). The newer CT technology identified 25 injuries in 24 patients for an incidence of 1.2% among the 2,023 blunt trauma admissions and 5.5% among the total patients screened with CTA. This was over a threefold increase in the incidence of blunt cerebrovascular injuries identified compared to older technology CT. There were no delayed presentations of clinical deterioration attributable to the missed diagnosis of cerebrovascular injuries. The blunt cerebrovascular trauma literature suggests that CTA as a replacement for digital subtraction angiography in the evaluation of cervical vascular trauma may not be appropriate, according to two recent prospective studies in blunt trauma patients.(27, 28) Miller and colleagues prospectively studied the outcome of at-risk patients sustaining blunt trauma that were evaluated based on an aggressive screening protocol.(27) Over a 2-year period, 216 (3.5% of all trauma admissions) were identified as high risk for blunt cerebrovascular injury and were screened. Angiography identified 24 patients with carotid and 43 patients with vertebral artery injuries. In comparison of CTA with angiography, CTA had a sensitivity of only 53%, leading the authors to conclude that CTA was an inadequate screening examination. Malhotra and colleagues performed a prospective parallel comparison of the diagnostic accuracy of digital subtraction angiography and CTA.(28) Of 119 patients evaluated with CTA, 92 patients underwent DSA. There were 23 DSA that identified 26 blunt cervical vascular injuries. Among the positive DSA patients, only 17 had positive CTA revealing only 19 of the 26 injuries. The remaining six studies were considered false negative. A further 10 of the 69 negative CTA were false-positive for a vascular injury. Due to poorly timed contrast or artifact, three CTA were not evaluable. The authors concluded that CTA should not be used as a screening tool for blunt cervical vascular injury due to the high false-negative and false-positive rate and the 20% rate of non-evaluable studies. In the setting of penetrating trauma, these shortcomings should be recognized and incorporated into practice. In their evaluation of 65 patients sustaining neck trauma with penetration of the platysma, Bell and colleagues described almost complete elimination of negative explorations for neck trauma in their trauma center with the use of CTA as a guide to decision making.(29) Inaba and colleagues reported a single-center prospective evaluation of multislice helical CTA for the initial evaluation of penetrating neck trauma in 106 patients.(30) CTA with multislice helical technique had a sensitivity and specificity for the detection of vascular or aerodigestive injury of 100% and 93.5%, respectively. CTA identified two tracheal and two carotid lesions requiring intervention in asymptomatic patients.

Conclusion
In centers with multi-detector CTA capabilities, the use of CTA in the initial evaluation of penetrating neck trauma can replace angiography; however, in the setting of a high index of suspicion

of vascular injury or artifact making the CT difficult to interpret, conventional angiography remains the gold-standard imaging study (Grade of recommendation: 1B).

Other Noninvasive Imaging
Duplex ultrasound utilizes B-mode ultrasound imaging with Doppler technology to assess pulsatile flow. Duplex ultrasound is used extensively in evaluating patients for carotid stenosis as well as in the follow-up after carotid endarterectomy and carotid stent placement. Duplex ultrasound has the advantages of being non-invasive, not requiring contrast agents, being low cost compared to other imaging modalities, rapid, and easily repeated. Fry and colleagues carried out a two-part study to evaluate duplex ultrasound in the setting of penetration of the platysma or blunt cervical spine fracture or neurologic deficit after blunt trauma.(31) In the first part of the study, both arteriography and duplex ultrasound were performed on 15 patients followed by duplex alone in 85 patients. An intimal flap was identified in 1 patient out of 15 during the first phase of the study. All modes of investigation—duplex, arteriography, and operative exploration—identified the injury. A total of eight vascular injuries were identified during both arms of the study with duplex demonstrating a 100% sensitivity and specificity. This data coupled with the benefit of saving $1,252 using duplex alone has led to duplex taking on a primary role in imaging zone II injuries for vascular involvement at the author's institution. Other studies comparing duplex ultrasound with confirmatory angiography have produced similar encouraging findings.(32, 33) In Fry's study, the imaging was performed by either one registered vascular technician or one vascular surgeon.(31) This may be challenging to perform in facilities that do not have continuous vascular technologists or radiologists in house capable of interpreting duplex exams. Other disadvantages of duplex ultrasound include the fact that the study is extremely user dependent, the possibility of missing a pseudoaneurysm involving the vertebral artery hidden within the vertebral bony canal, the difficulty of evaluation of vascular structures in the setting of a hematoma or subcutaneous emphysema, and the difficulty with evaluation of zones I and III vessels in some author's experience.(5)

The experience of magnetic resonance angiography is limited to several small series and case reports. MRA has been shown to be applicable in adults for evaluation of the carotid arteries for occlusive disease.(34, 35) Friedman and colleagues prospectively evaluated MRA in 37 blunt trauma patients to determine the frequency of vertebral artery injury with cervical spine trauma.(36) A total of nine patients had arterial abnormalities on MR imaging. This tool seems to be an effective technique for vascular imaging in the setting of hemodynamically stable trauma patients. Levy and colleagues reported a 95% sensitivity for diagnosis of dissection with MRA compared to 84% sensitivity with traditional MR imaging techniques.(37) MRA has the disadvantages of time consumption, problems with monitoring during the study, difficulty in acquisition of the study during night and weekend hours at some centers, limitations with MR imaging with retained metallic debris, and the technique of imaging can give a false-negative result due to high-signal-intensity hematoma being indistinguishable from intraluminal flow enhancement.(5) MRA continues to evolve as

an imaging technique for vascular trauma. Gadolinium-enhanced MRA allows rapid, comprehensive examination of the supraaortic arterial system through the circle of Willis.(38) This technology may play a role in the future emergency imaging of penetrating neck trauma to evaluate for vascular pathology.

Conclusion
The use of duplex ultrasound is a reasonable adjunct to physical exam in a facility with extensive experience with the use of cervical duplex imaging. Further investigation should be made on the use of MRA in evaluating cervical vascular injury before a conclusive recommendation can be made (Grade of recommendation: 2C).

MANAGEMENT

Indications for an Emergent Neck Exploration
In 1956, Fogelman and colleagues published that a series of 100 patients from Parkland Hospital sustained penetrating injuries to the neck.(39) In their series of patients, if urgent surgical exploration was employed, the mortality rate was 6% compared to a 35% mortality for delayed operative exploration or nonoperative management. This led to the adoption of mandatory exploration of penetrating neck trauma that violated the platysma. The Fogelman study was published during a time when no invasive imaging options existed to evaluate for vascular injury. This is distinctly different than the current setting of regional trauma centers with multiple imaging modalities available to interrogate the neck vasculature. The military operational environment may still provide a setting in which mandatory exploration of penetration of the platysma in zone II may be appropriate.(40) Although the exploration of zone II penetrating neck wounds is straightforward with low morbidity, this approach has a high negative exploration rate. There is up to a 56% negative exploration rate with the practice of mandatory neck exploration for penetrating trauma, and several prospective studies have demonstrated the safety of the selective management of penetrating neck injuries. (41–44) The first prospective evaluation to study the selective approach included 29 patients observed after sustaining a penetrating neck injury that demonstrated no sign of vascular or aerodigestive injury.(42) None of the patients required a delayed neck exploration for a missed injury. Adjunctive testing to include angiography ($n = 4$), esophagography ($n = 5$), esophagoscopy ($n = 2$), and laryngoscopy ($n = 1$) was utilized in the evaluation of a fraction of the patients. Biffl published a prospective evaluation of their experience with the management of penetrating neck trauma over an 18-year period.(44) Of 312 patients, 207 presented without symptoms and were observed with only 40% undergoing adjunctive testing. Only one patient (0.5%) who sustained an ice pick injury in zone II of the neck required a delayed exploration. The authors concluded that selective management of penetrating neck injuries is safe. Although Meyer's report of 5 patients with 6 major injuries in 113 asymptomatic neck injuries concluded that major injuries may be missed if a selective approach is employed for penetrating neck injuries, most authors support a selective management technique in the setting of no symptoms.(45, 46)

Conclusion
A selective management approach employing inpatient observation and adjunctive imaging is safe in the setting of penetrating neck trauma without symptoms (Grade of recommendation: 1B).

> The patient presented was taken emergently to the operating room for exploration of the ipsilateral neck. The decision to emergently explore the patient's neck was made based on the fact that the patient was hypotensive during her initial evaluation, and the paramedic's report indicated a large quantity of blood was lost at the scene.

Combined Carotid Artery and Aerodigestive Injury
If preoperative imaging or endoscopy has identified an aerodigestive organ injury combined with a carotid arterial injury, the risk of postoperative blowout at the site of arterial repair is increased. The principles of management of combined cervical vascular and aerodigestive injuries, based on single-center case reports, include prompt identification of both injuries, buttress of the injured visceral repair to decrease the rate of leak, and separation of the repairs using local tissue flaps.(47) The interposition of a vascularized portion of mobilized sternocleidomastoid (SCM) is the recommended method for tissue interposition in patients with cervical vascular and esophageal injuries.(47) The SCM has a tripartite blood supply from the occipital, superior thyroid, and suprascapular arteries.(48) This allows for the SCM to be raised from either its superior or its inferior site of insertion and rotated in one of two separate directions. Applications for the SCM muscle flap include interposition in all three zones of the neck for combined injuries. Levine and colleagues described a case of a carotid–esophageal fistula after PTFE interposition graft repair of a zone I carotid injury with cervical esophageal repair and sternocleidomastoid muscle flap interposition.(49) The patient represented 3 weeks postoperatively with hematemesis and profound anemia. Endoscopy was normal; however after repeat recurrent, brisk hematemesis, angiography and esophagography revealed carotid pseudoaneurysm and a pseudodiverticulum of the cervical esophagus. Prompt exploration with prosthetic removal, vessel ligation, and exteriorization of the esophagus was performed without further complications. Despite SCM muscle flap interposition, this patient developed a carotid–esophageal fistula that was diagnosed only after arteriography, highlighting the importance of vascular imaging in the clinical setting of recent or remote vascular repair in proximity to a hollow viscus with evidence of bleeding. Angiography is the study of choice in this clinical setting. Identification of active extraluminal bleeding or pseudoaneurysm formation mandates reexploration for vascular control and definitive management.

Conclusion
The principles of the management of a combined cervical vascular and aerodigestive injury include early identification, repair, and separation of the repairs using a vascularized pedicle of sternocleidomastoid muscle (Grade of recommendation: 2C).

Endovascular Stenting

The experience with stent graft placement via endovascular techniques for penetrating vascular trauma is increasing rapidly. Conclusive data in the form of retrospective or prospective trials comparing endovascular and open approaches to the management of these injuries are not currently available, however. Pardodi and colleagues reported the use of stent graft treatment of two ICA and four common carotid artery penetrating injuries over a 7-year period with no procedure-related complications.(50) In a series of eight blunt and penetrating trauma patients, Diaz-Daza described the successful use of endovascular therapy with embolization of five extracranial carotid or vertebral artery branch vessels and the deployment of one Wallstent (Boston Scientific, Natick MA) in the ICA in the penetrating trauma subgroup of patients (51) There were no procedure-related complications and a patient with a GSW to the neck with preoperative hemiplegia had complete resolution at 8-month follow-up. McNeil and colleagues from Willford Hall Medical Center reported endovascular stent graft occlusion of a pseudoaneurysm of the cervical ICA after penetrating trauma located 6 mm below the skull base using a 9 French Wallgraft (Boston Scientific, Natick MA).(11) The reports of other techniques for endovascular management of ICA traumatic lesions include arterial occlusion with detachable balloon or coils, endovascular embolization, and the double-stent technique of exclusion of pseudoaneurysms.(52) When carotid occlusion is planned for definitive management of traumatic lesions, maneuvers to ensure that the patient will tolerate the decrease in cerebral perfusion from the injured side are recommended and include temporary balloon occlusion test, contralateral angiography to ensure adequate filling from the noninjured side, somatosensory-evoked potential monitoring, and regional cerebral oxygenation after compression of the ipsilateral common carotid artery.(53–55) Endovascular therapy for penetrating neck trauma offers possible advantages over open surgical exploration and repair, including minimal tissue damage, limited vascular occlusion time, ease of distal control near the skull base, less pain, and shorter convalescence. Endovascular techniques may become the management of choice of certain traumatic lesions to the intracranial carotid artery and now play a significant role in the management of extracranial carotid trauma especially for injuries in zone III.(51, 53) Zone III vascular injuries are an ideal anatomic location for the application of endovascular treatment due to the difficulty with exposure of the carotid at this level and the difficulty in achieving distal vascular control. The decision to approach the management of an extracranial carotid injury using endovascular techniques requires a multidisciplinary approach involving the patient/surrogate decision maker, trauma surgeon, neurosurgeon, and interventionalist. Proponents for endovascular treatment of zone III injuries site poor flow characteristics with certain extracranial to intracranial bypass techniques, the requirement of a craniotomy for intracranial carotid exposure, and very limited combined experience among most neurosurgeons and vascular surgeons as reasons for supporting this approach.(11)

Conclusion

Only small case series and case reports exist regarding the use of endovascular management for penetrating carotid artery injuries.

Given the available literature, the use of endovascular techniques in the management of penetrating carotid artery trauma should be based on resources available at the institution providing care, the experience of the interventionalist, the patient's hemodynamic status, and characteristics about the injury that might make an endovascular procedure advantageous, such as locations at the base of the skull that are difficult to expose. More definitive studies must be performed before more conclusive guidance regarding endovascular management of penetrating cervical vascular trauma can be offered (Grade of recommendation: 2C).

Injuries with Neurologic Deficits

Controversy has existed regarding the management of patients with neurologic deficit and extracranial cerebrovascular injuries for many years.(56) Older accounts of carotid arterial injury recommended ligation in the setting of neurologic deficit due to the concern for conversion of an ischemic stroke to a hemorrhagic stroke.(56, 57) However, since Cohen's report, several series of patients have been reported that demonstrate favorable outcomes when repair is attempted in this subset of patients. Liekweg and Greenfield reported eight patients with carotid artery injury and preoperative neurologic deficit and combined their data with historical cases from the literature to compare the results of ligation and arterial repair.(58) The authors identified 40 patients with neurologic deficit exclusive of coma and showed that revascularization in 34 patients led to favorable neurologic outcome in 85% of cases. The cohort of patients treated with ligation ($n = 6$) sustained only a 50% rate of favorable outcomes. The subset of patients presenting with preoperative coma after correction of hypotension uniformly did poorly regardless of intervention. The authors recommended that exclusive of comatose patients, carotid repair should be attempted in the setting of a neurologic deficit. Liekweg and Greenfield's recommendation for carotid arterial repair in the setting of neurologic deficit has been supported by multiple authors since its publication.(59–62) In regard to patients with dense neurologic deficits, Teehan and colleagues observed that patients with carotid injury and Glasgow coma scale (GCS) score less than 8 is predictive of poor prognosis, regardless of whether the vessel is repaired or ligated.(63) Other authors support that with comatose patients sustaining carotid arterial injury, mortality is high and neurologic outcome is similar whether the injury is managed with repair or ligation.(1, 61) Du Toit and colleagues identified 5 patients in a series of 151 patients sustaining penetrating trauma to the brachiocephalic, common, or internal carotid arteries that were found to have evidence of conversion of an ischemic to a hemorrhagic infarct on postmortem examination.(59) The authors could not identify any contributing factor that was predictive of hemorrhagic infarction. Du Toit's series illustrates the potential risk of conversion of an ischemic to hemorrhagic stroke with carotid arterial repair. Several other cases have been reported of hemorrhagic conversion of infarctive strokes after penetrating carotid trauma.(59, 61, 64, 65) Murray and colleagues reported a case of a patient sustaining a GSW to the carotid artery with contralateral hemiparesis and arteriographic diagnosis of a left common carotid artery pseudoaneurysm and arteriovenous fistula which was subsequently primarily repaired.(65) Postoperative persistent coma led to CT which revealed hemorrhagic stroke, severe

edema with midline shift. The patient progressed to brain death. The authors recommend that postinjury coma established for more than 3–4 h despite resuscitation and correction of hypothermia, ischemic infarct on CT, or the absence of retrograde flow from the distal arterial stump may be considered contraindications for repair due to the risk of hemorrhagic conversion of an ischemic stroke.

Conclusion
Based on the sited literature, the approach of carotid arterial repair in the setting of neurologic deficit is preferred over ligation with the exception of prolonged coma after injury (Grade of recommendation: 2A)

OPERATIVE ISSUES

Exposure
As in the management of all trauma patients, the algorithm of airway, breathing, circulation, disability, and exposure guides initial care. The patient presenting with active bleeding, expanding hematoma, or absence of flow in the carotid artery distal to the injury requires emergency intervention. In the patient presenting with active exsanguination, direct digital pressure may allow temporary hemostasis. Blind clamp placement into a traumatic wound should never be performed. Insertion of a single or multiple balloon-tipped catheters may allow for tamponade and temporary hemostasis while the patient is transported to the operating room. Recommendations for exposure of the injured carotid artery are based on expert opinion developed over the last century, as our experience with vascular trauma has increased. The type of incision used to expose the carotid artery depends on the anatomic neck zone injured. Zones I and III of the anterior neck represent areas that are more difficult to gain proximal and distal vascular control. Figure 5.2 demonstrates the multiple incisions that may be required based on the location of the carotid injury.(66) Adjunctive procedures/extensions to the standard anterior neck incision include but are not

limited to sternotomy, clavicular resection, mandibular subluxation, and vertical mandibular osteotomy. If neck exploration is performed for possible carotid artery injury, prepare both groins into the operative field to provide greater saphenous vein for autologous vascular conduit if needed.

Conclusion
The optimal operative exposure of a stab wound to the carotid artery is based on expert opinion and should be individualized based on the patient presentation (Grade of recommendation: 2C).

> The neck of the patient presented was explored through an incision along the anterior border of the sternocleidomastoid muscle. This approach for exposure of the patient's injury was chosen due to the fact that the injury was located in zone II of the anterior neck. Injuries at this location are readily exposed, and proximal and distal control can be obtained with relative ease via this standard neck incision. Injuries in zone I or III may require adjunctive maneuvers noted above to obtain proximal and distal control and allow for arterial repair.

Repair
Although the use of endovascular techniques in vascular trauma is expanding, open repair remains the gold standard for management of carotid injuries due to penetrating trauma. After proximal and distal vascular control has been obtained and the injury is identified, the choice of technique of repair and choice of conduit if needed must be made. The injury site should be inspected and all nonviable vessel wall should be debrided to normal, healthy tissue. In the setting of small lacerations to the carotid due to low-velocity mechanism, the technique of interrupted or running arteriorrhaphy utilizing a double-armed, nonabsorbable, monofilament suture, such as 5–0 or 6–0 polypropylene, is appropriate. If a complete vessel transaction has occurred, or if debridement of
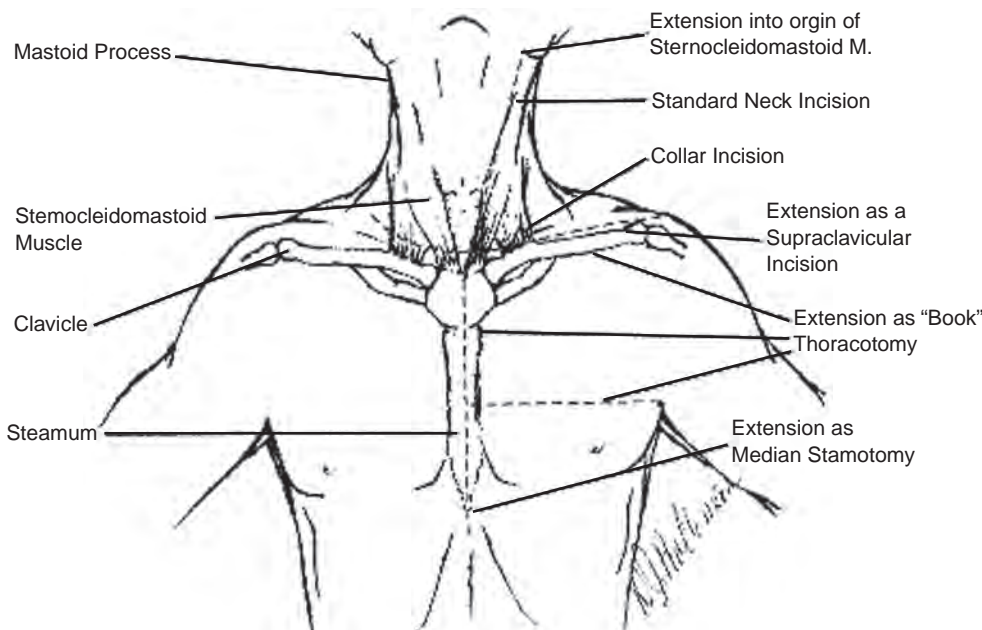

Figure 5.2 Possible incisions for surgical exploration of penetrating carotid artery injury, based on neck zone penetrated.

(*Source:* Feliciano DV.(66))

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nonviable vessel wall has led to two completely separate ends of the vessel, primary repair may not be feasible due to the resultant tension at the anastomosis. If a vascular conduit is needed for reconstruction, autologous vein, such as saphenous vein, harvested from the thigh is the conduit of choice. This is especially true in the setting of reconstruction in a contaminated field. If a synthetic material is necessary, surgeon preference typically dictates whether Dacron/polyester (DuPont, Wilmongton, DE) or Goretex/expanded polytetrafluoroethylene (W L Gore, Flagstaff, AZ).

> The carotid artery of the patient presented was repaired primarily. This repair was selected because the wall defect was 0.5 cm in greatest dimension with healthy tissue at the wound edges. Primary repair was easily performed using 6–0 polypropylene suture.

Shunting

Expert opinion states that mandatory shunt placement during expeditious operative management of carotid trauma is unnecessary. Just as in elective carotid endarterectomy, shunt use is typically based on surgeon preference.(55) Shunting may be helpful for temporary flow restoration in difficult areas to gain adequate distal control such as zone III penetrating injuries or when additional time is required for procurement of saphenous vein for vascular repair.(67)

Conclusion

There is no role for mandatory intraoperative shunt placement during the management of penetrating carotid trauma; however, certain situations that require extended time such as zone III injuries or the need to procure autologous vein may allow for benefit from temporary flow restoration (Grade of recommendation: 2C).

> No shunt was used in the patient presented. The patient's carotid arterial injury was small and amenable to rapid, primary repair. A shunt in this situation would have been time consuming and would have provided no benefit.

OUTCOME

Penetrating injuries to the neck carry a mortality ranging from 3 to 10%.(68, 69) When the carotid artery is injured, the mortality associated increases to 20% as a result of either exsanguination or neurologic deficit from cerebral ischemia.(60) Areas more difficult to manage such as zone III penetrating wounds with carotid injury carry higher mortality ranging between 8.6 and over 30%.(70) In the setting of neurologic deficit exclusive of coma, a favorable outcome can be expected with repair in 85% of patients.(58) However, with either ligation or revascularization of patients with carotid penetrating injuries who are comatose on presentation, the mortality exceeds 70%.(58)

SUMMARY

Penetrating wounds to the carotid artery can present with life-threatening hemorrhage or uncommonly with subtle or no signs of vascular injury. Thorough physical examination as well as a high index of suspicion for such injuries will lead the astute clinician

to adequately screen for carotid injuries in at-risk patients and eliminate missed injuries. In large, tertiary-care referral centers, multiple tools exist to assist in the diagnosis of carotid injury including digital subtraction angiography, computed tomographic angiography, and duplex ultrasound. Once considered mandatory, operative exploration for certain penetrating neck injuries is now limited to symptomatic patients with accessible lesions or in the setting of limited resources with long evacuation times such as in the rural or deployed military setting. The rapid expansion of endovascular techniques from elective to traumatic vascular lesions has led to its application in penetrating neck trauma. Endovascular treatment of carotid injuries may one day become the treatment of choice of some types of carotid injuries to include areas difficult to operatively expose, such as zones I and III. A multiple-center prospective trial comparing traditional surgical management with endovascular management of penetrating neck trauma with imaging evidence of vascular injury would be helpful in advancing this field.

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6   Cervical Spine Fracture with Quadriplegia

Eric B Harris, James Lawrence, Jeffrey Rihn, Li Gang, and Alexander R. Vaccaro

A 47-year-old woman was admitted to the emergency room 2 h after a fall from a horse. She was breathing comfortably and was appropriately immobilized at the scene with a backboard and collar. At initial presentation, the patient was awake and alert. She had no visible lacerations or contusions about her head and neck. Vital signs were stable with a systolic blood pressure of 80 mmHg and heart rate of 54 bpm. Physical exam reveals no chest, abdomen, or pelvic trauma and no gross extremity fractures were identified. Neurologic examination revealed the patient to be alert and oriented to person, place, time, and circumstance but unable to voluntarily move any extremity. Closer examination revealed no motor function in any extremity with the exception of a shoulder shrug. The patient had no sensation to pinprick or light touch below the neck. Rectal tone was flaccid, and bulbocavernosus (BC) reflex was absent. Deep tendon reflexes were similarly absent, and the patient had no myoclonus. Intravenous methylprednisolone was started with a 30 mg/kg bolus followed by 5.4 mg/kg infusion.

Plain radiographs of the cervical spine and a computed tomography (CT) scan of the cervical spine demonstrated a transverse fracture through the C2 body extending into the C1–C2 facet joints. The C1–C2 facet joints were grossly disrupted with approximately 14 mm of distraction (Figures 6.1–6.5). The remainder of the patient's imaging studies showed no abnormality. The patient was kept in a rigid collar and placed on a kinematic bed awaiting surgical stabilization.

The patient was taken to the operating room for posterior C1–C2 fusion using C2 pedicle and C1 lateral mass screws and iliac crest autograft (Figure 6.6a–d). Three days postoperatively the patient had a return of BC reflex with no change in neurologic examination.

CERVICAL SPINE FRACTURE WITH QUADRIPLEGIA: GENERAL OVERVIEW

Demographics and Epidemiology of C-spine Fracture with Quadriplegia

There are approximately 180,000–230,000 patients living with a spinal cord injury (SCI) in the United States today. Based on emergency room admission data, the incidence rate of SCI in the United States is between 30 and 40 new injuries per one million population per year. It is estimated that another 10–20 fatal injuries per one million population per year occur in which the patient expires before reaching the hospital. Grossman et al. reported that cervical spine injury (CSI) account for 4.3% of trauma admissions.(1) In the pediatric population, motor vehicle accidents are the cause of cervical spine trauma in about 38% of cases. A recent study by Yanar et al. reviewed 8,401 pedestrian injuries caused by automobiles, and 178 patients (2.1%) had CSI. Their study showed that the incidence of CSI increased with age (0.3% in the age group 14 years and younger, 2.2% in the group 15–55 years, 3.7% in the group 56–65 years, and 4.4% in the group older than 65 years).(2)

Clinical Evaluation

As with any trauma patient, individuals presenting with a suspected neck injury should have an initial evaluation according to advanced trauma life support guidelines.(3–5) Once the patient's airway, breathing, and circulatory status are stable and any life-threatening conditions stabilized, secondary survey of the spine should be performed. During initial assessment, patients suspected of having any spine injury should be log-rolled carefully and the entire spine, from occiput to sacrum, palpated for tenderness or step-off hematoma, ecchymosis, or skin breaks should be noted. A careful neurologic examination including mental status, cranial nerves (CNs), detailed motor and sensory evaluation, and deep tendon reflexes should be documented. Finally, a rectal examination assessing rectal tone and volition and BC reflex should be performed and documented by a member of the spinal surgery team. The American Spinal Injury Association (ASIA) worksheet seen in Figure 6.7a and b is a comprehensive tool for documentation of the neurological examination.

The patient presented had no motor function in any testable myotome but demonstrated normal sensation in the C3 dermatome. She had no sacral sparing. Her ASIA classification was therefore C3, which is the last level with normal function bilaterally, ASIA A, or complete injury.

Imaging Studies

Good quality radiographs of the cervical spine including an anteroposterior (AP) view, a lateral view in which the top of the T1 vertebral body is visible, and an open-mouth odontoid view should be obtained on all patients suspected of having a CSI. This quick, inexpensive study can exclude most unstable injuries, with a sensitivity as high as 92% in adults and 94% in children (6) (Level 1C evidence). The diagnostic performance of helical computed

Figures 6.1 The fracture appears grossly stable. There is straightening of the cervical lordosis. Scattered degenerative changes are present. The prevertebral soft tissue is unremarkable. External fixation device is noted.

Figures 6.2 The fracture appears grossly stable. There is straightening of the cervical lordosis. Scattered degenerative changes are present. The prevertebral soft tissue is unremarkable. External fixation device is noted.
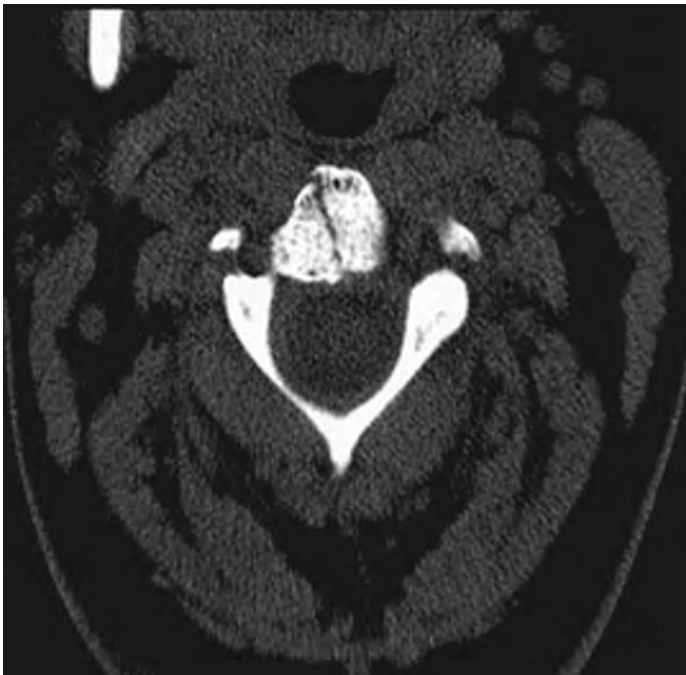
Figures 6.3 Axial CT image demonstrates a sagittal split through the body of C2. There is posterior translation of the right fragment relative to the left.
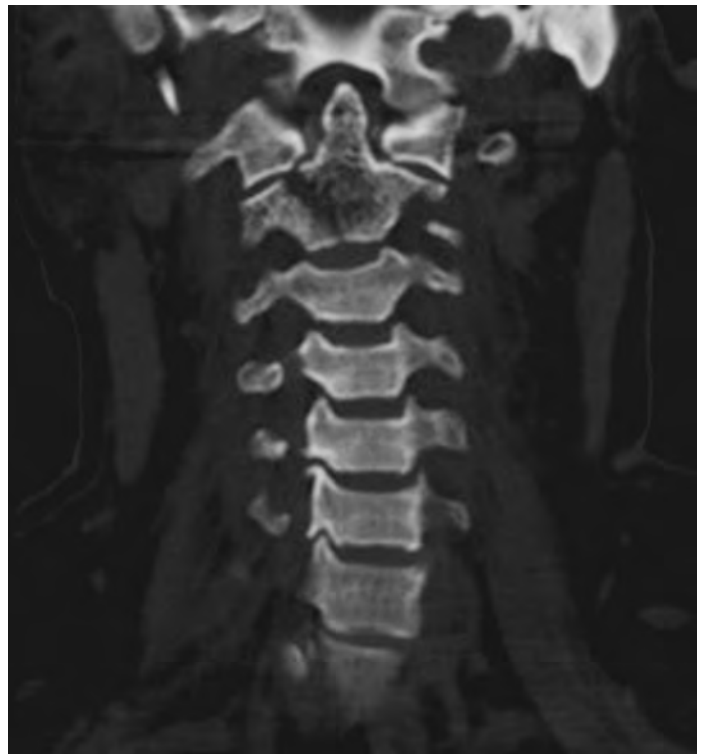
Figures 6.4 Coronal cuts of the CT scan show a vertical fracture line lateral to the dens which extends through the entire C2 body. Some degree of comminution as well as lateral displacement of the right side of the vertebral body is noted.

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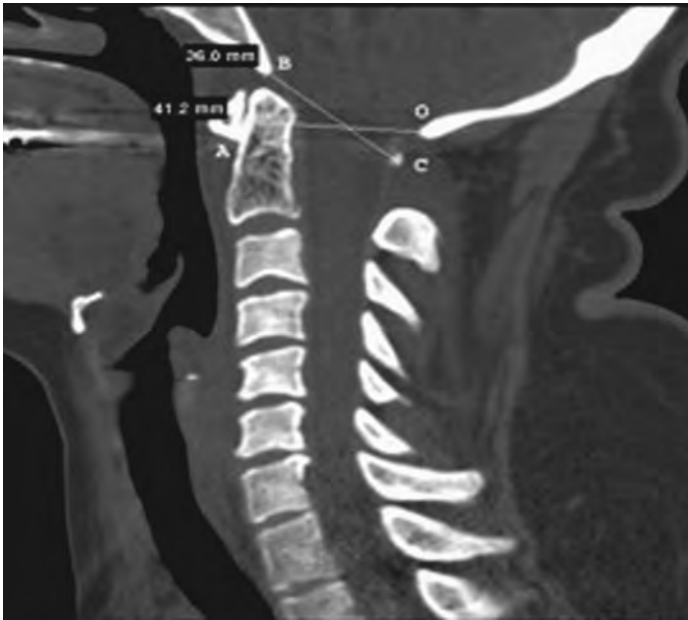
Figures 6.5 The Power's ratio measurements of a lateral extension radiograph of the cervical spine. The distance between the basion (B) and the anterior aspect of the posterior ring of C1 (C) is divided by the distance between the opisthion (O) and the posterior aspect of the anterior arch of C1 (A). The Power's ratio (BC/OA) for this radiograph is 0.90.
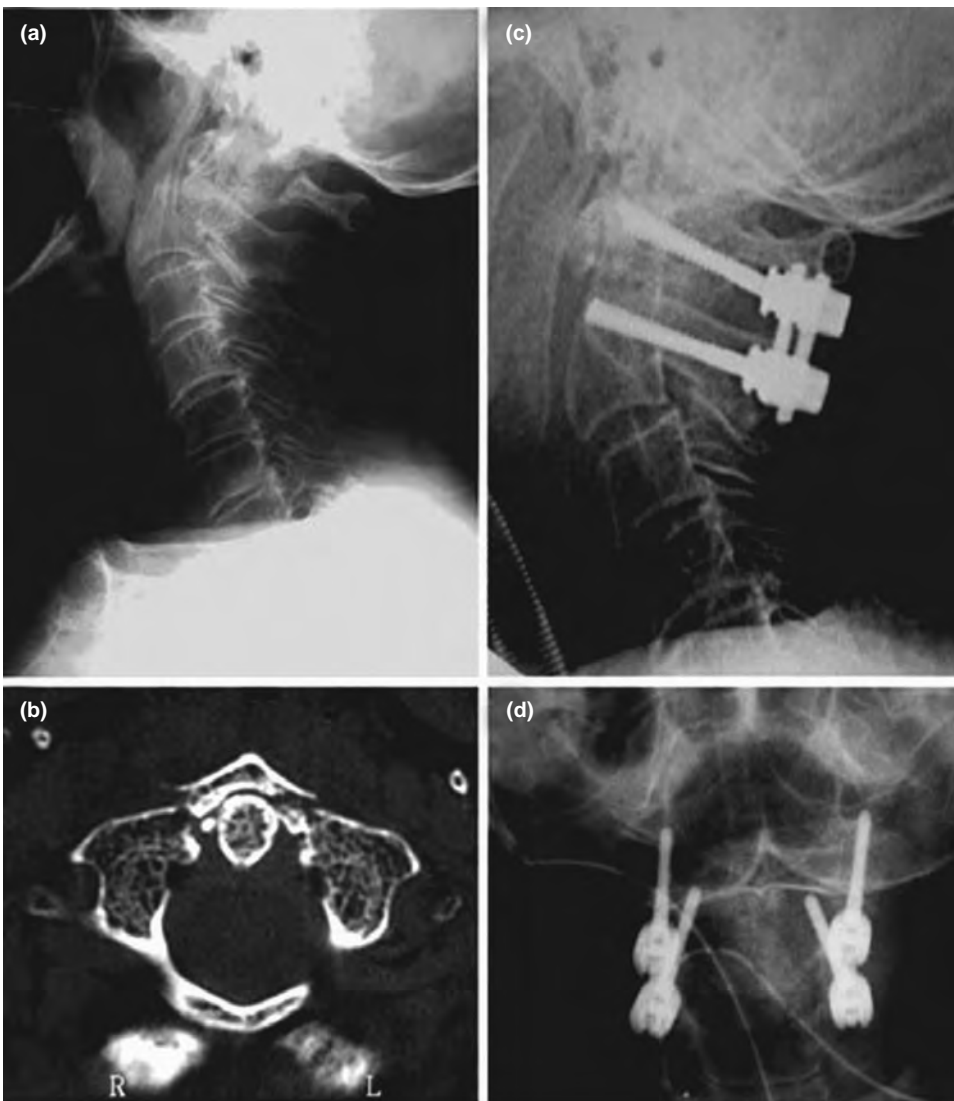
Figures 6.6 (a) A fracture of the dens and of the anterior arch of the atlas with C1 dislocation posteriorly is seen on this lateral preoperative radiograph. (b) The transaxial CT section at the level of C1 demonstrates a fracture of the anterior arch of the atlas. (c) Lateral postoperative radiograph following reduction and posterior atlanto-axial fusion. (d) Transoral postoperative radiograph

Figure 6.7a ASIA Neurological classification worksheet.

tomography (HCT) scanners may be even better, with reported sensitivity as high as 99% and specificity 93% (7–8) (Level 1A evidence) but plain radiographs provide a baseline study for comparison when following these patients over time and, therefore, should still be obtained even when a CT is performed. The few injuries missed on plain radiographs or CT are usually purely ligamentous and may only be detected with magnetic resonance imaging (MRI) or dynamic plain radiographs. Finally, up to 16% of patients with cervical spine trauma have noncontiguous spinal fractures and, even more frequently, fractures at C1–C2 are associated with a remote subaxial cervical spine fracture. The imaging studies of these patients should be carefully reviewed for such injuries.

When interpreting imaging studies in patients with suspected cervical spine trauma, a systematic approach should be utilized. The AP view should be assessed for alignment, visible fractures, and distraction at any level. On the lateral view, sagittal alignment is noted and attention paid to the anterior vertebral line, posterior vertebral line, and spinolaminar line which should all demonstrate a smooth curve with no step-off or discontinuity. Angulation of greater than 11° compared to adjacent segments or translation of greater than 3.5 mm is highly suspicious for injury. Further radiographic or advanced imaging studies should be obtained. Analysis of the prevertebral soft tissues is also important and may allow the diagnosis of subtle cervical injuries on the lateral view. A good rule of thumb for evaluating these tissues is that the prevertebral soft tissue shadow should measure about 6 mm anterior to C2 and 22 mm anterior to C6. Assessment for atlanto-occipital instability on the lateral plain X-ray view may be assessed utilizing one of many methods of measurements such as the Power's ratio, Harris Rule of 12, Lee's X line, and the measurements of Wiesel and Rothman.(9–11) The Power's ratio is popular and useful to evaluate occipitoatlantal alignment. The ratio of a line drawn from the basion to the anterior border of the posterior arch of the atlas and a line from the opisthion to the posterior border of the anterior arch of the atlas should be less than 1. A Power's ratio greater than 1 suggests an anterior atlanto-occipital dislocation. To assess the integrity of the atlanto-axial joint, the atlanto-dens interval should be examined. This measurement, made from the posterior aspect of the anterior C1 ring to the anterior cortex of the dens, should be less than 3 mm in adults and 4 mm in children. Higher values suggest disruption of the transverse ligament and further imaging, specifically, MRI, should be obtained to rule out pure soft-tissue injury at this level. Finally, the open-mouth odontoid view allows for further assessment of the atlanto-axial complex. The dens should be evaluated for fracture on this view, and the lateral masses of C1 should be

MUSCLE GRADING

0 total paralysis

1 palpable or visible contraction

2 active movement, full range of motion, gravity eliminated

3 active movement, full range of motion, against gravity

4 active movement, full range of motion, against gravity and provides some resistance

5 active movement, full range of motion, against gravity and provides normal resistance

5* muscle able to exert, in examiner's judgement, sufficient resistance to be considered normal if identifiable inhibiting factors were not present

NT not testable. Patient unable to reliably exert effort or muscle unavailable for testing due to factors such as immobilization, pain on effort or contracture.

ASIA IMPAIRMENT SCALE

☐ **A = Complete:** No motor or sensory function is preserved in the sacral segments S4-S5.

☐ **B = Incomplete:** Sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5.

☐ **C = Incomplete:** Motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3.

☐ **D = Incomplete:** Motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade of 3 or more.

☐ **E = Normal:** Motor and sensory function are normal.

CLINICAL SYNDROMES (OPTIONAL)

☐ Central Cord
☐ Brown-Sequard
☐ Anterior Cord
☐ Conus Medullaris
☐ Cauda Equina

STEPS IN CLASSIFICATION

The following order is recommended in determining the classification of individuals with SCI.

1. Determine sensory levels for right and left sides.

2. Determine motor levels for right and left sides.
    Note: in regions where there is no myotome to test, the motor level is presumed to be the same as the sensory level.

3. Determine the single neurological level.
    This is the lowest segment where motor and sensory function is normal on both sides, and is the most cephalad of the sensory and motor levels determined in steps 1 and 2.

4. Determine whether the injury is Complete or Incomplete (sacral sparing).
    If voluntary anal contraction = No AND all S4-5 sensory scores = 0 AND any anal sensation = No, then injury is COMPLETE. Otherwise injury is incomplete.

5. Determine ASIA Impairment Scale (AIS) Grade:

    Is injury Complete?   If YES, AIS=A Record ZPP
    NO   (For ZPP record lowest dermatome or myotome on each side with some (non-zero score) preservation)

    Is injury motor Incomplete?   If NO, AIS=B
    YES   (Yes=voluntary anal contraction OR motor function more than three levels below the motor level on a given side.)

    Are at least half of the key muscles below the (single) neurological level graded 3 or better?
    NO → AIS=C   YES → AIS=D

    If sensation and motor function is normal in all segments, AIS=E
    Note: AIS E is used in follow up testing when an individual with a documented SCI has recovered normal function. If at initial testing no deficits are found, the individual is neurologically intact; the ASIA Impairment Scale does not apply.

Figure 6.7b ASIA Neurological classification worksheet.

aligned with the superior articular processes of C2 with no significant overhang.

If the plain radiographs reveal any abnormality, or clinical suspicion is high, CT may be helpful in further defining the injury. CT also is helpful when the lower cervical spine cannot be visualized adequately on plain radiographs. Fine-section CT, 1.25–2.50-mm slice thickness, with coronal and sagittal reconstruction, is ideally suited to evaluate the cervical spine. CT is also indicated in patients with altered consciousness who are undergoing head CT.

In patients with neurologic deficits, particularly when CT does not show a reason for the deficit, patients with deteriorating neurologic status, or cases of suspected posterior ligamentous injury not evident on plain radiographs or CT reconstructions, MRI is indicated. Careful evaluation of the posterior ligamentous complex, intervertebral disks, and any spinal cord compression is possible with today's high-quality MRIs (12–16) (Level 1B evidence).

> The patient presented above had gross abnormality seen on plain radiographs. CT scan was obtained to better define the nature of the fracture and facilitate surgical planning. Should the X-rays have been questionable, CT would certainly still be appropriate given the neurologic examination. A preoperative MRI was not necessary in this case as it would not have affected ultimate treatment.

Complete Versus Incomplete Injuries in Cervical Spine Injury

CSI with neurologic trauma may include various complete and incomplete cord injuries and even brainstem injury. CN injuries, especially CN VI, VII, IX, XI, and XII, occur with skull-base and occipitocervical trauma.

An injury to the spinal cord is defined as complete when there is no voluntary motor or sensory function below the level of injury. There is no voluntary anal sphincter contraction, rectal tone, or anal sensation. Otherwise, an injury is considered incomplete. In incomplete neurologic injuries of the cervical spine, the most important prognostic variable relating to neurologic recovery is the completeness of the lesion. Younger patients and those with either a central cord or Brown–Sequard syndrome, who have an incomplete SCI, have a more favorable prognosis for recovery. Large retrospective studies suggest that there is no high-level evidence to date supporting "high-dose steroid administration, routine early surgical intervention, or surgical decompression in stenotic patients without fracture."(17) (Level 2C evidence). While earlier surgical decompression in the setting of an incomplete lesion has been shown to lead to faster recovery of neurologic function, early mobilization, briefer hospital stays, and fewer complications in patients with preexisting spondylosis sustaining minor trauma (16, 18), there is no evidence proving this to be true in patients sustaining significant multisystem and more severe neurologic injuries. Studies are currently underway at several centers to attempt to resolve this question.

Neurogenic Shock Versus Spinal Shock

Neurogenic shock, sometimes called vasogenic shock, results from the disruption of autonomic nervous system control over vasoconstriction. Under normal conditions, the autonomic nervous system keeps the muscles of the veins and arteries partially contracted. At the onset of most forms of shock, further constriction is signaled. However, the vascular muscles cannot maintain this contraction indefinitely. A number of factors, including increased fluid loss, central nervous system trauma, or emotional shock, can override the autonomic nervous system control. The veins and arteries immediately dilate, drastically expanding the volume of the circulatory system, with a corresponding reduction of blood pressure.

In 1750, Whytt defined spinal shock as a loss of sensation accompanied by motor paralysis with initial loss but gradual recovery of reflexes, following an SCI. He noted that reflexes caudal to the SCI are depressed or absent, while those cephalad to the lesion remain unaffected. The term "shock" in spinal shock varies significantly from that in neurogenic shock as it does not refer to circulatory collapse. In 2004, Ditunno et al. proposed a four-phase model for spinal shock.(19) In Phase 1, all reflexes below the SCI are absent, or weak. This phase typically lasts for about 1 day. The first reflex to appear following SCI is the delayed plantar reflex (DPR). This abnormal reflex is elicited by strongly stroking the sole of the foot along the lateral side and then going medially across the metatarsal heads. The toes flex and relax in a delayed fashion. This reflex is often accompanied, or followed subsequently, by return of the BC reflex. Other cutaneous reflexes such as the anal wink (AW) and cremasteric reflex (CM) also return, albeit weakly, near the end of Phase 1. Phase 2 occurs over the next 2 days and is characterized by strengthening of the cutaneous reflexes but with persistent absence of the deep tendon reflexes (DTRs). The exception to this rule occurs in some elderly patients who may experience return of the DTRs and Babinski's (BS) sign during this phase. It is postulated that this is secondary to preexisting subclinical myelopathy. Phase 3 lasts from 4 to 30 days after SCI. Most DTRs return during this period, usually beginning with the ankle jerk (AJ) reflex, closely followed by BS sign, and finally, the knee jerk (KJ). While the timing of the return of these reflexes generally follows the described order, it is important to understand that there is a high degree of variability in both the order and the absolute timing with which these reflexes return. Finally, Phase 4 occurs between 1 and 12 months post-injury. This phase is characterized by hyperreflexia produced with minimal stimulation. The DPR usually disappears during Phase 4, while the cutaneous (AW, CM, BC), deep tendon reflexes (AJ, KJ), and Babinski's sign become hyperactive.

Understanding spinal shock is most important in research efforts directed toward mitigating the often irreversible damage and consequent disability which occurs secondary to SCI. Further study of the anatomic and physiologic changes which occur during all phases of spinal shock may hold the key to better future treatments for this devastating injury.

> Three days post-injury, the patient described above had return of the BC reflex but no other reflexes. The return of this reflex but absence of other cutaneous reflexes signified she was still in Phase 1 of spinal shock.

Injuries by location and treatment

The treatment of a patient with a CSI, regardless of location, is initiated at the scene of the injury. Without exception, all victims of trauma are suspected to have a cervical injury until proven otherwise. CSI has been closely linked to the presence of severe head injury, high-energy mechanism, or a focal neurologic deficit.(20–22) In suspected injuries of the upper cervical spine, an adequate airway and ventilation must be established because upper SCI can lead to diaphragmatic and intercostal paralysis with respiratory failure. In addition, large retropharyngeal hematomas can cause upper airway obstruction. Nasotracheal intubation and cricothyroidotomy are fastest in the acute setting and require less cervical spine motion than direct oral intubation techniques.(10, 23, 24) Once the patient's airway, breathing, and circulation are addressed, initial stabilization of the cervical spine may be accomplished with the application of a rigid cervical collar, a spine board, and sandbags.

Occipital Condyle Fractures

Occipital condyle fractures are usually associated with head trauma, skull-base fractures, lower CN palsies (CN XII), and other upper cervical injuries.(25) These fractures can be very difficult to diagnose with X-ray alone and are better recognized on CT scan. Nondisplaced impaction and unilateral injuries can generally be treated with an orthosis for 6–12 weeks. Fracture patterns resulting in occipitocervical instability require halo or surgical stabilization.(26) Standard surgical intervention for this type of injury is a posterior occipitocervical instrumented fusion.

Atlanto-occipital Dislocation

The incidence of atlanto-occipital joint dislocation, depicted in the lateral radiograph seen in Figure 6.8, is estimated to be between 5 and 8% in motor vehicle crash fatalities.(27–29) These injuries account for 19–35% of all deaths from cervical spine trauma, are caused by high-energy trauma, and are frequently associated with other life-threatening conditions such as brainstem injury, vertebrobasilar artery injury, subarachnoid hemorrhage, and posterior pharyngeal wall disruptions. Improvements in on-site resuscitation and emergency transportation have increased the number of patients who survive this catastrophic injury reflected in the fact that over 80% of reported cases of occiput-C1 dislocations have been reported since 1975. Children younger than 12 years of age are uniquely predisposed to this injury because their atlanto-occipital joints are flatter and because their head-to-body weight ratio is significantly greater than in adults.(30)

Atlanto-occipital dislocations are considered universally unstable. These injuries should be expeditiously reduced and immobilized with a halo vest in patients too medically unstable to undergo immediate surgery. Traction should be avoided. Definitive treatment consisting of posterior instrumented occipitocervical arthrodesis should be performed as soon as the patient is able to undergo surgery. Improved occipital plates and upper cervical poly-axial screw instrumentation techniques allow for excellent outcomes with operative reduction and stabilization (31, 32) (Level 1C evidence).

Figure 6.8 Occipitocervical dislocation. Note the significant space between the skull base and the C1 ring. This devastating injury has a high rate of mortality.

C1 Fractures

Fractures of the atlas represent 10% of all cervical spine fracture, and five distinct fracture patterns are generally recognized. The most common injury is the posterior arch fracture, which usually occurs at the junction of the lateral masses. The mechanism of this injury is typically hyperextension. Associated injuries of C2, such as an anterior inferior body fracture or spondylolisthesis of the axis, should be ruled out if this mechanism of injury is suspected. A second pattern of fracture is the floating lateral mass fracture which is a fracture anterior to the lateral mass on one side and posterior to the lateral mass on the contralateral side. Lateral mass fractures are usually a result of a combined axial loading and lateral bending mechanism. Associated fractures often include lower cervical facet fractures. Jefferson fractures are characterized by fractures of the anterior and posterior rings of C1 leading to bilateral fragments that tend to displace laterally. Combined displacement of the lateral masses greater than 6.9 mm seen on the open-mouth odontoid radiograph is associated with rupture of the transverse ligament. Transverse or horizontal fractures through the anterior tubercle of C1 may result from hyperextension injuries, possibly due to forceful contraction of the superior oblique portion of the longus colli. Lastly, transverse process fractures of C1 may be unilateral or bilateral and are usually the result of a forced lateral compressive (ipsilateral) injury with a contralateral avulsion fracture. This pattern may be associated with laminae fractures in the lower cervical spine.

Treatment of most C1 injuries is nonoperative and includes a cervical orthosis, Minerva cast, (11) or halo stabilization, typically utilized for 3 months. . Exceptions to this rule include patients with other spinal injuries or inability to comply with orthosis use. Commonly associated injuries which may necessitate early surgical intervention include fractures of the dens, especially in the elderly population. If the transverse ligament through its midportion is ruptured, early C1–2 arthrodesis should be considered. Fractures of the posterior arch of the atlas by themselves are

Figure 6.9 Type IIa Hangman's fracture. This subtype of hangman's fracture will displace if traction is placed. Reduction consists of extension and gentle compression. Treatment is surgical.

stable injuries and amenable to closed treatment with a cervical orthosis. Lateral mass fracture with minimal displacement may be treated with rigid orthoses or halo immobilization.

C2 Hangman's Fractures (C2 Traumatic Spondylolisthesis)

Hangman's fracture, or traumatic spondylolisthesis of the axis, is the second most common fracture of C2. This fracture, shown in Figure 6.9, is characterized by a bilateral arch fracture of the C2 pars interarticularis with variable displacement of C2 on C3. Although the pars fracture is typically bilateral, it is rarely symmetrical because of a rotational component associated with an extension injury.(33–37) Type I hangman's fractures have less than 3 mm of C2–3 subluxation and heal reliable after 6 and 12 weeks in an orthosis. The stability and optimal treatment strategy for a Type II hangman's fracture is less clear. In a Type II hangman's fracture, extension forces may lead to disruption of the anterior longitudinal ligament, posterior longitudinal ligament, and C2–C3 disk.(33) Type II fractures have more than 3 mm of C2–3 subluxation with variable degrees of angulation. Type II fractures may or may not be unstable depending on the degree of deformity and soft-tissue disruption present. Type IIa fractures often have a larger C2–3 kyphotic angle compared to Type II fractures and are associated with disk space distraction without significant fracture displacement. This pattern is unique in that it tends to displace in traction and therefore is reduced with

gentle extension and compression. Type IIa fractures are considered unstable injuries. Type III hangman's fractures are associated with C2–3 facet dislocation and are highly unstable. The C2–3 disk, anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), and facet capsules are all disrupted.

Treatment of hangman's fractures varies from institution to institution. Types I, II, and IIa fractures may almost always be treated nonoperatively in the acute setting, while Type III fractures should always be addressed surgically. Types I, II, and IIa fractures can be treated by gentle reduction, sometimes necessitating several days of traction, followed by 12 weeks of collar or halo immobilization depending on the degree of instability. Successful treatment with hard-collar immobilization alone has been reported. Type III fractures may be irreducible through closed means, and surgical treatment with posterior open reduction and C2–3 fusion and instrumentation may be necessary.(38)

The goals in surgical treatment of Type III hangman's fractures are reduction, stabilization, and maintenance of alignment. Surgical stabilization for nonunion of a Type II hangman's fracture has been described using both anterior and posterior approaches. The anterior approach, which has the advantage of technical ease and a relatively short fusion construct, involves a C2–C3 diskectomy with interbody fusion and plating.(39-41) Many posterior options for fixation of the isthmus fracture component of a hangman's fracture have been described. Direct repair of the pars fracture with a screw across the fracture line has been reported to have the advantage of preserving motion of the axis.(42, 43) Direct pars repair, however, does not address instability at the level of the disk if present. Posterior C1–C3 wiring techniques have been described, but these techniques require postoperative halo immobilization and fusion involvement of C1 which is less than optimal. One of the best posterior fixation options in this setting is the use of a C2 pars or pedicle screw and a C3 lateral mass screw bilaterally. This technique addresses the detached posterior arch of C2 by pinning the fractured pars while simultaneously addressing instability at the C2, C3 disk.(44, 45) Regardless of the choice of surgical approach, careful attention must be paid to achieving adequate reduction and stability. Outcomes in these patients appear to be affected by the quality of the reduction. Watanabe et al. (46) reported that persistent postoperative neck pain may be related to residual kyphosis, residual translation, and fracture extension into the C2 inferior facet.

C2 Avulsion Fractures

Avulsion fractures involving a small portion of the anterior–inferior vertebral body are often referred to as extension teardrop fractures. These stable fractures should not be confused with subaxial flexion–compression teardrop fractures which are highly unstable injuries associated with disruption of the posterior ligamentous structures and a high incidence of SCI. C2 extension teardrop fractures can be treated with a hard collar.(47)

Odontoid Fractures

Odontoid fractures constitute approximately 20% of cervical fractures.(48) Motor vehicle accidents account for most injuries in patients between the ages of 16 and 34 years. Falls account for most injuries in patients older than age 55 and younger than age

15. In the elderly population, this injury is associated with an in-hospital mortality rate of 35%. Anderson and D'Alonzo created the following classification system:

Type I odontoid fractures describe a fracture involving the tip of the dens. These may result from a severe rotational or lateral bending force that causes an avulsion of bone through the alar and apical ligaments. Other distraction injuries must be ruled out. This type of fracture is stable and can be treated with a cervical orthosis in the absence of occipitocervical instability.

Type II odontoid fractures occur through the "waist" of the dens without extension into the C2 body and have highly variable rates of nonunion. A plain lateral radiograph and a sagittal CT cut depicting this fracture are seen in Figure 6.10a and b. Risk factors for nonunion include age greater than 50, more than 5 mm displacement, 9° of angulation, fracture redisplacement, and smoking. Young patients with nondisplaced or minimally displaced Type II dens fractures in patents without other significant risk factors for nonunion may be treated in a halo. Orthosis treatment alone should be undertaken with the expectation of a nonunion and is reserved for elderly patients with low functional demand. The long-term functional outcomes in elderly patients with odontoid nonunion are largely unknown.(49, 50) Displaced and significantly angulated Type II fractures are often treated with posterior atlanto-axial instrumentation and fusion with autogenous bone graft or osteosynthesis with an anterior odontoid screw, which theoretically preserves more motion (48) (Level 1B evidence). Posterior C1–2 fusion provides immediate, reliable stabilization and can be accomplished using wiring techniques, transarticular screw fixation, or segmental fixation utilizing C1 lateral mass and C2 pars or pedicle screws.(51) Posterior fusion techniques eliminate approximately 50% of cervical rotation; so in select fractures, anterior fracture fixation should be considered. Anterior screw fixation of acute odontoid fractures results in healing rates of approximately 90% and theoretically preserves C1–2 motion. However, anterior screw fixation requires near-anatomic fracture reduction, absence of significant comminution, and orientation of the fracture plane from anterior–superior to posterior–inferior. Midsubstance transverse ligament rupture, severe comminution, and an anterior–inferior to posterior–superior fracture pattern are contraindications to odontoid screw fixation.

Type III fractures extend into the body of C2. In marked contrast to Type II fractures, this pattern has a union rate which is much more predictable than Type II fractures with nonoperative immobilization; a consequence of larger surface of area and more vascular cancellous bone. This type of fracture may often be reliably managed with a halo fixator or cervical orthosis.(49, 52)

Cervical Burst Fractures and Compression–Flexion Fractures

Cervical burst fractures occur primarily through an axial load with subsequent compressive failure of the vertebral body and bony retropulsion into the spinal canal. The fracture pattern is similar to burst fractures in the thoracolumbar spine. These fractures are considered unstable and are often associated with SCI depending on the degree of bony ligamentous disruption. A compression–flexion fracture occurs due to a combination of an axial load associated with a flexion force. Figure 6.11 is a lateral radiograph of a patient with a flexion–compression type injury. Vaccaro et al. described the subaxial injury classification (SLIC) and

Figure 6.10a Lateral radiograph and sagittal CT cuts depicting a displaced Type II odontoid fracture. This injury may be managed with halo immobilization or C1–2 fusion.

Figure 6.11 Lateral radiograph showing a flexion–compression injury with a burst fracture of C5. Treatment of these fractures is based upon the SLIC scoring system developed by Vaccaro et al. in 2007.

Figure 6.10b Lateral radiograph and sagittal CT cuts depicting a displaced Type II odontoid fracture. This injury may be managed with halo immobilization or C1–2 fusion.

column disruption on available imaging studies is determined and points assigned. The injury is described as no abnormality (0 points), compression plus or minus burst fracture (1 or 2 points, respectively), distraction injury (3 points), or rotation/translational injury (4 points). Next, the integrity of the disko-ligamentous complex (DLC), represented by both the anterior and posterior ligamentous structures as well as the intervertebral disk, is assessed and 0 points assigned for an intact complex, 1 point for isolated interspinous widening, and 2 points for interspinous widening with disk disruption. Finally, neurologic status of the patient is determined and 0 points assigned if the patient is neurologically intact, 1 point for a root injury, 2 points for a complete injury, 3 for an incomplete injury, and an additional point is added if there is continuous cord compression present in the setting of a neurologic deficit. Points are tallied and surgical versus nonsurgical treatment is determined by a threshold value of the total score. If the total is between 1 and 3, nonoperative treatment is often recommended. If the total is > = 5, operative treatment is often recommended consisting of realignment, neurologic decompression as necessary, and stabilization. This system has been validated, is easy to use, and is a valuable tool in clinical decision making(53) (Level 1C evidence).

Compression–flexion fracture occurs in varying degrees of severity.(54) Simple cervical compression fractures occur through compressive failure of the anterior vertebral body with preservation of the posterior body, the PLL, and the posterior column. The vertebral body is wedged, and there may be minimal kyphosis with no canal compromise. Patients are usually neurologically

severity scale in 2007. This scale relies upon three components to assist in clinical decision making in cervical spine injured patients. First, injury morphology as determined by the pattern of spinal

Figure 6.12a These images show a unilateral facet dislocation at C6–7. Expeditious reduction and fixation of this injury may lead to improved neurologic and functional outcomes.

Figure 6.12b These images show a unilateral facet dislocation at C6–7. Expeditious reduction and fixation of this injury may lead to improved neurologic and functional outcomes.

intact and in the absence of significant deformity can be treated in an orthosis for 10–12 weeks.(49) A higher grade compression–flexion fracture results in a large triangular bony fragment at the anterior–inferior aspect of the vertebral body with tensile failure of the posterior osteoligamentous complex resulting in kyphosis and retrolisthesis of the remaining vertebral body into the spinal canal. When severe, these injuries are highly unstable and associated with a high incidence of SCI. The treatment of cervical burst fractures and compression–flexion fractures is similar and is based on the neurologic status and the degree of mechanical stability. In the past, many of these fractures were managed nonsurgically with days to weeks of prolonged traction in a rotorest bed depending on severity, followed by halo immobilization. Traction was required because halo vests are not capable of maintaining axial distraction. However, because of the morbidity associated with prolonged bed rest and the advent of modern instrumentation techniques, these methods have become largely obsolete. If the fracture is associated with neurologic injury, instability is inferred and operative treatment is generally recommended. In the neurologically intact patients, the clinical treatment strategies are based more upon the estimation of mechanical stability. The degree of kyphosis and status of the posterior osteoligamentous complex contribute to the estimation of mechanical instability. (55) The fractures deemed stable are often treated with a brief period of traction followed by a halo vest or an orthosis. Surgical treatment of unstable burst or compression–flexion fractures generally involves an anterior corpectomy, structural grafting, and rigid plate fixation with or without posterior stabilization.

Posterior stabilization should be strongly considered in patients with osteopenia, in fractures with frank disruption of the posterior osteoligamentous complex, or in injuries involving multiple motion segments.

Although not subaxial, the case study patient has an injury most consistent with a compression–flexion mechanism. The fracture extends through the C2 body and into the disrupted C1–C2 facet. This type of injury, with such significant displacement of the disrupted facets, is highly unstable and should be addressed surgically. C1–C2 posterior fusion is the correct choice for treatment since there is no evidence of further instability at the occipitocervical junction or in any of the subaxial segments. Use of iliac crest autograft increases the likelihood of a successful fusion.

Facet Injury (Dislocation and Fracture)
Cervical facet injuries represent a spectrum of bony and disko-ligamentous injury that range from nondisplaced fractures, to subluxation (with or without fracture), to complete dislocation. Facet dislocations, shown on CT and radiograph in Figure 6.12a and b, are the result of high-energy flexion–distraction force. Unilateral dislocations are often associated with 25% vertebral subluxation and unilateral radiculopathy. Bilateral dislocations are associated with 50% vertebral subluxation and SCI. Unilateral facet injuries are not common and represent around 6% of all CSI.(56–58) Dvorak et al. (59) reported that the most common facet injury was the minimally or nondisplaced superior articular facet fracture (35%), followed by the displaced superior articular facet fracture (18%).

Treatment of facet dislocation has remained controversial. The initial step in management of an awake, alert, and appropriately responsive patient is consideration for a closed reduction using cranial tong traction.(60) Although safe closed reduction has been reported with weights up to 150 lbs, reduction is usually achieved using weights ranging from 40 to 70 lbs depending on the type of dislocation, spinal level, and body habitus of the patient. The decision to apply more weight depends on surgeon comfort and experience. Based upon current clinical evidence, immediate closed reduction in awake and alert patients with complete motor and sensory loss is recommended (Level 1C evidence). For patients who are neurologically intact or have an incomplete SCI, treatment depends on surgeon preferences and individual injury characteristics. For awake, alert, and responsive intact and incomplete patients with an acute SCI, strong consideration should be given to performing a closed skeletal reduction prior to obtaining an MRI. MRI has been used by several authors to better identify soft-tissue injuries such as accompanied disk or ligament ruptures, which correlate with instability of the involved segment. (28, 61, 62) MRI evidence of a clinically significant disk herniation prior to, or after, a closed reduction influences the choice of surgical approach (anterior) to remove compression on the spinal cord followed by cervical reconstruction. Consideration for the extent of surgery, i.e., combined or single-stage approach depends on the degree of instability present. Degree of translation has also been studied (28) as a relative indication for surgical treatment of facet injuries.(59, 63–67)

Facet fractures are very common and easily missed on plain radiography. The superior facet is involved in 80% of affected patients. Inferior facet fractures tend to begin at the base of the lamina and are associated with laminar fractures. Most facet fractures are unilateral, small, nondisplaced, and without subluxation or kyphosis and can be successfully treated with an orthosis for 10–12 weeks. Unilateral facet fractures involving more than 40% of the height of the articular process or with associated injuries to the DLC seen on MRI may be unstable and may be predictive of failure of nonsurgical treatment.(67, 68) Bilateral fractures are also associated with shear injuries across the disk and may be unstable.

The lateral mass fracture separation is a unique pattern of injury that results in a "floating lateral mass."(69–71) This occurs when there is a simultaneous fracture of the pedicle and the lamina of a single vertebra. Dvorak's (59) series included four of these injuries, all treated with posterior instrumentation. Fracture separation of the lateral mass may be challenging to manage due to the frequent need to immobilize two motion segments.(58, 72) In 80% of patients, the floating lateral mass is associated with subluxation at the caudal interspace (e.g., a C6 floating lateral mass is often associated with a C6–7 subluxation). This fracture pattern was originally described as a two-level injury with the need for a two-level stabilization procedure, i.e., a C5–7 fusion for a C6 floating lateral mass.(73) However, single-level stabilization has been advocated when soft-tissue injury demonstrated on MRI scan is clearly at one level (C6, C7 in the above-mentioned case) with no signal abnormality at the adjacent level (C5, C6).(74)

Distraction–Extension Injuries
Distraction–extension injuries (Figure 6.13) are associated with ankylosing conditions of the spine such as ankylosing spondyllitis,

Figure 6.13 Extension distraction injuries as seen in this figure are most common in patients with ankylosing spondylitis or other disease processes which lead to stiffening of the spine. They occur secondary to the effect of a long lever arm acting on the rigid spine.

diffuse idiopathic skeletal hyperostosis (DISH or Forestier's disease),(75) and multilevel ankylosed spondylosis in elderly patients. The stabilizing ligaments of the spine are ossified and fracture leads to significant instability despite minimal bony displacement. The fused cervical spine behaves more like a long bone when fractured due to the long level arms adjacent to the injury. These injuries occur most commonly at the cervicothoracic junction and are frequently missed because they occur in low-energy falls. Plain radiographs are often inadequate or benign-appearing secondary to osteopenia. When the diagnosis is missed, attempts to mobilize the patient can lead to devastating neurologic deterioration. Patients with inflammatory ankylosing conditions are also prone to increased bone bleeding, and neurologic deterioration can result from a compressive epidural hematoma.

Imaging and immobilization of patients with ankylosing conditions of the spine should be aggressive after even minor trauma with minor neck pain. Plain radiographs, CT, and/or MRI are often required to identify a fracture, and the entire spine should be imaged to rule out noncontiguous spinal injuries. The patient should be immobilized during diagnostic imaging, and if a fracture is identified, a custom fitting halo vest should be applied, as surgical intervention is considered. Cervical traction should be avoided unless used cautiously to realign a significantly displaced injury. Surgical treatment is recommended for most patients in whom it can be medically tolerated.(76–77) Extreme care should be used during positioning to prevent iatrogenic injury and to account for any preexisting kyphosis. A posterior approach is usually preferred for reduction and stabilization, and instrumentation
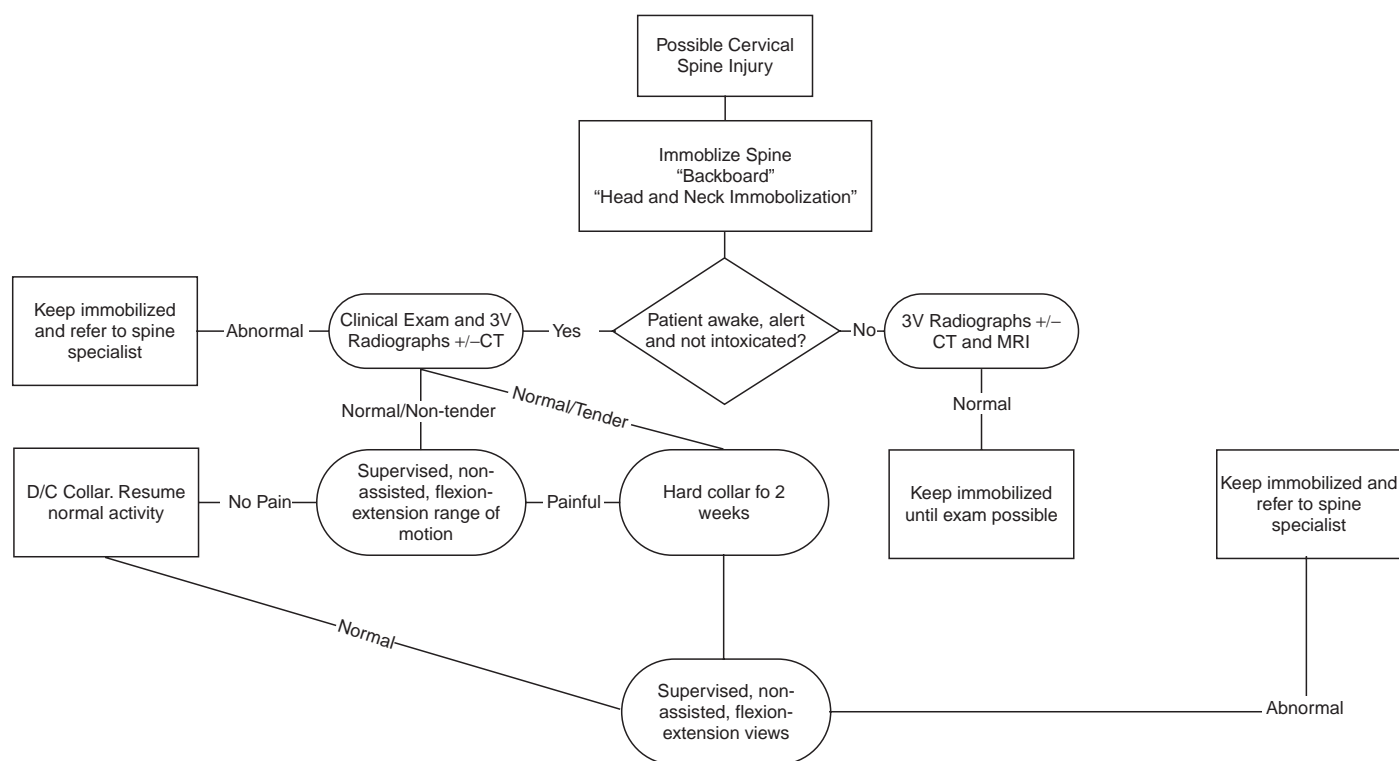
Figure 6.14 A basic algorithm for clearance of trauma patients with suspected cervical spine trauma.(88)

should be extended to multiple levels above and below the injury to counteract long lever arms and compensate for poor bone quality. Supplemental anterior instrumentation may also be required.

Injuries Associated with Cervical Spine Trauma
Noncontiguous spinal injuries can occur in 6–10% of patients, and these fractures can be easily missed in the presence of head injury, upper CSI, or cervicothoracic injury. An Atlas fracture is associated with up to a 50% incidence of concurrent cervical spine fractures. (30, 78, 79) Facial and head injuries are also commonly seen in conjunction with fractures and ligamentous disruptions of the craniocervical junction. It is therefore important to obtain appropriate imaging studies of the entire spine to rule out these injuries. Another commonly nonbony or ligamentous injury associated with cervical subaxial trauma is injury to the vertebral artery. The presence or absence of such an injury may dictate the choice of surgical approach in an unstable cervical spinal injury. Vaccaro et al. noted a 19.7% incidence of vertebral artery injury (VAI) found by magnetic resonance angiography in 61 cervical spine trauma patients.(80) Veras et al. also reported that MR angiography is a helpful test to rule out vascular injury in cervical spine trauma patients.(81) In Cothren and coworkers' report, 18% of 69 patients with VAI and cervical spine trauma sustained injuries to the upper cervical spine (82, 83), including a case of blunt VAI leading to a cervical fracture diagnosis.(82) Blunt VAI is typically associated with cervical spine fractures involving subluxation, extension into the foramen transversarium, or involvement of the upper three cervical elements. Vertebral artery thrombosis (VAT) is also closely associated with cervical spine trauma. Importantly, the absence of neurologic symptoms in a patient with cervical spine

fracture does not rule out VAT. VAT associated with cervical spinal injury occurs with similar frequency in both neurologically intact and motor-incomplete patients but is significantly more common in motor-complete SCI.(84)

Protocol for C-spine Clearance
The evaluation of the cervical spine with quadriplegia or in an unconscious trauma patient is a difficult and controversial topic in trauma management. Plain radiographs combined with conventional CT may not adequately detect unstable ligamentous CSI. Weinberg et al. (85) presented two cases where conventional C-spine clearance protocols, utilizing plain X-rays and CT, failed to identify significant ligamentous C-spine injuries. A delay in diagnosis or a missed spinal injury can lead to delays in treatment, thereby increasing the risk of neurological deterioration with the potential devastating sequela of quadriplegia. Therefore, in the unconscious trauma patient who has sustained a high-risk injury mechanism injury, the routine use of MRI in addition to plain X-rays and CT is recommended to more fully evaluate disko-ligamentous integrity. The HCT scan is the most sensitive, specific, and cost-effective modality for screening for cervical spine bony injuries, but it is not an effective modality for screening for cervical ligamentous injury. The indications for MRI include the presence of abnormalities seen on CT, the presence of neurologic deficits, cervical pain or tenderness on examination, or the inability to clear the cervical spine in the obtunded patient. Using current state-of-the-art technology, the definition of SCI without radiographic abnormality has been altered to include SCI without bony injuries or ligamentous injury.(86, 87) A basic algorithm for clearance of the cervical spine is included in Figure 6.14.

Platzer et al. retrospectively evaluated the protocol for cervical spine clearance at an Austrian trauma center utilizing a prospectively collected trauma database (89) (Level 1A evidence). All trauma patients who were admitted to this Level I trauma center between 1980 and 2004 were included in the study. Standard radiographs including either a single lateral or AP, lateral and open-mouth odontoid views were obtained on each patient. If radiographs or clinical suspicion pointed toward an injury, further studies including functional flexion/extension views, oblique views, CT scan, or MRI were obtained. Eighty-one patients underwent radiological evaluations beyond the screening lateral or three-view series. This protocol led to correct diagnosis in 107 patients (91%). The protocol failed to detect significant CSI in 11 patients (9%). Two patients with missed injuries had poor technical quality three-view radiographs while six had only a single lateral view obtained. Ligamentous injuries were missed in three patients who had both three-view radiographs and a CT scan.

The authors concluded that cervical CT scan was the most efficient imaging tool in detecting skeletal injuries, showing a sensitivity of 100%. The sensitivity of a single cross-table lateral view appeared was only 63%. Because plain radiographs plus CT alone failed to detect ligamentous injury in 6% of patients, they recommended routine use of functional radiography or MRI to avoid missing injuries, especially in patients with distracting injuries.

Pharmacotherapy

The optimal pharmacotherapy for patients with acute SCI remains the subject of debate and controversy. The lack of high-quality human studies in this field has led to an absence of definitive treatment algorithms. Hence, there are no uniformly accepted recommendations regarding the medical treatment of acute SCI including the use or nonuse of systemic medications. Pharmacotherapy aims to minimize damage caused by the secondary mediators of SCI. Based on existing basic science theories, three medications have undergone formal clinical testing in multicenter, prospective study formats. These pharmacologic agents are methylprednisolone, ganglioside GM1, and naloxone.

The rationale behind the use of high-dose methylprednisolone is based upon the theory that prevention of oxidative phosphorylation will decrease permanent damage from SCI. Used in a high dosage regimen (30 mg/kg body weight bonus over 15 minutes, followed by 45 minutes delay, then 5.4 mm/kg/h for 23 h), methylprednisolone dose not act by its glucocorticoid mechanism; rather, it functions as an antioxidant. The National Acute Spinal Cord Injury Study—Part II (NASCIS 2), published in 1990, showed statistically significant benefits in SCI patients treated with high-dose methylprednisolone compared to patients treated with placebo if administered within 8 h of injury (Level 2A evidence).

There are, however, significant criticisms of the NASCIS 2 study that have centered on two main issues. First, the improvements seen in the steroid group did not correlate with any significant functional improvement compared to placebo and likely reflected merely a more rapid return of nerve root rather than spinal cord function. Secondly, high-dose methylprednisolone has significant detrimental effects, including increased bleeding,

Recommendation	Grade of Recommendation
Plain cervical radiographs as a screening tool	1C
Helical CT scan for suspected cervical fracture	1A
MRI for evaluation of soft-tissue structures	1B
Avoidance of use of steroids or surgical intervention in patients with stenosis and no fracture	2C
Occipitocervical fusion for patients with atlanto-occipital dislocation	1C
Operative fixation of displaced or angulated Type II odontoid fractures	1B
Use of the SLIC classification system to determine the need for surgical stabilization	1C
Immediate closed reduction of cervical facet dislocations in awake, alert patients with complete motor and sensory loss	1C
Platzer et al. protocol for cervical spine clearance	1A
Use of high-dose methylprednisolone for treatment of SCI	2A

increased infections, osteonecrosis, and detrimental effects on spinal fusion. Although none of these effects was determined to have significance in the NASCIS 2 study, these theoretical risks combined with the questionable neurologic benefits achieved have led to nonuniform acceptance of this protocol by spine specialists. This is juxtaposed by near universal application of the protocol, likely secondary to fear of legal implications if the protocol is not followed. In 1997, the NASCIS 3 protocol was published, which involved a minor alteration in the duration of methylprednisolone dosing. The controversy over the efficacy of high-dose methylprednisolone recommended by NASCIS 2 was not resolved by NASCIS 3. Several papers have been published which highlight confounding factors, which were omitted from the NASCIS data, such as accurate documentation of medical and surgical treatment at different centers, functional outcomes, and complications. Further investigation into the efficacy of this protocol is warranted.

GM1 ganglioside is another pharmacologic agent which has been evaluated for its potential in SCI treatment. GM1 is believed

to exert its action at the white matter level in the spinal cord. A preliminary study published in 1991 showed good results in a few patients in a single spine center. A follow-up, multicenter-controlled trial performed at 28 institutions, however, failed to show benefit with the use of GM1 ganglioside at 26 weeks or 52 weeks post-injury. Secondary to this report, enthusiasm for this agent has waned. Another theory has emerged which attempts to explain the role of opiate receptors and opiate antagonists in SCI patients. According to observations by different authors, naloxone, which is a μ-subtype antagonist, has neuroprotective properties. This agent appears to have a multifactorial, multilayered activity which is poorly understood, and further studies are necessary to evaluate fully the possibility of the use of naloxone in acute SCI.

The patient described received high-dose steroids as described by the NASCIS 2 study. Because she presented only 2 h after her injury, she received steroids for a total of 24 h. Again, it should be noted that no functional improvement was described in patients receiving high-dose methylprednisolone, and the risks of administering steroids are significant. When asked, many physicians administer steroids only to avoid potential legal action, highlighting the controversy of this protocol and the need to further investigate its use.

CONCLUSIONS

Proper evaluation and early treatment of CSI are of paramount importance in returning trauma patients to pre-injury function if possible depending of their neurologic status. A clear understanding of the mechanisms and patterns of CSI coupled with an appropriate imaging workup and physical examination allows timely, directed management of these injuries maximizing the potential for early rehabilitation and spinal stability. Current technologies facilitate early diagnosis and refined surgical techniques and implants provide the opportunity for early mobilization. Ongoing research may someday provide improved solutions for SCI patients. In the mean time, prevention of further damage to the spinal cord can be maximized through a thorough understanding of the basic concepts and principles of emergency spinal management.

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7 Blunt thoracic aortic injury
David Wisner

A 37-year-old restrained male driver is admitted to the emergency department after being involved in a head-on, high-speed collision with another car. There is no airbag deployment. He is initially stable from both a hemodynamic and respiratory standpoint. On exam there is a thoracic seatbelt sign, bilateral chest wall tenderness, and gross deformity of his left thigh with visible limb shortening. His resuscitation room chest X-ray shows a blurred aortic knob and a large left hemothorax. His pelvis X-ray demonstrates a complex left acetabular fracture. A left chest tube is placed with prompt return of 700 cc of blood.

After his initial trauma evaluation, he develops severe progressive hypoxemia requiring endotracheal intubation. He then undergoes a noncontrast computerized tomography (CT) scan of the head and cervical spine followed by a contrast-enhanced CT of the chest and abdomen using a multidetector helical scanner. He is found to have a left-sided pulmonary contusion and an aortic laceration at the isthmus with a pseudoaneurysm that extends proximally to the level of the left subclavian orifice. A grade II splenic laceration with minimal perisplenic fluid and a left acetabular fracture are identified on the abdominal CT. There is a moderate size pelvic hematoma without active contrast extravasation. Plain X-ray of the left leg shows a comminuted midshaft femur fracture

During CT scan, his systolic blood pressure falls to 80/40 mmHg, and he is immediately given a 2 l bolus of Ringer's lactate with normalization of his blood pressure to 130/80 mmHg within 15 minutes of infusion. The chest tube output has been 100 cc since placement 20 minutes ago, and a repeat chest X-ray shows no change in his mediastinal hematoma or residual hemothorax. He is immediately transferred to the intensive care unit where a left tibial traction pin is inserted for femoral traction.

After 1 h, his blood pressure remains normal, and he is started on a continuous esmolol infusion and his heart maintained between 70 and 90 bpm. A radial artery catheter is placed, and his systolic blood pressure remains less than 110 mmHg. Over the next 12 h, he remains hemodynamically normal, and approximately 16 h after arrival, he is taken to the operating room for diagnostic aortography and placement of an endovascular stent graft. Post-deployment angiography demonstrates coverage of the aortic injury with the proximal graft extending to but not occluding the left subclavian orifice. Postoperatively, he remains neurologically intact. His pulmonary status improves, and he is eventually extubated on postoperative day 5. A repeat CT angiogram is done on postoperative day 7 and demonstrates the stent graft in good position without evidence of migration or endoleak.

INTRODUCTION

Blunt injury to the thoracic aorta describes a collection of injuries ranging in severity from small intimal tears of unclear clinical significance to complete disruption that results in immediate exsanguination. Although blunt aortic injury was first reported by Vesalius in 1557, modern understanding of the severity and natural history of the disease is usually attributed to Parmley in 1958. He reviewed 296 autopsy and clinical cases of blunt traumatic aortic injury and noted that initial survival was less than 15%. In addition, one third of those with aortic rupture who survived transport to a hospital died within 24 h.(1) The description by Parmley was certainly an important step in our understanding of these injuries, but it is important to remember that most of the cases in his series were deaths, modern angiography was not available, and that only injuries with the most obvious of findings present on plain radiography were diagnosed antemortem. Accordingly, while some of the implications of the Parmley study remain true today, others do not.

Blunt thoracic aortic injury most commonly results in a transverse tear in the aortic wall. In the most severe form, full thickness circumferential injury results in immediate exsanguination. Lesser injuries also occur and include those isolated to the intima and media. Innovations in imaging technology have only recently highlighted these lesser degrees of aortic injury, and their true clinical significance remains unclear. It is likely that many are injuries that were always present but that we can only now detect, suggesting that specific treatment may be unnecessary.(2) Although traumatic dissections also occur, they are uncommon, a point which emphasizes the fact that the basic underlying pathology is aortic rupture and hemorrhage rather than dissection with aortic branch occlusion. In most cases of full thickness injury, free rupture and exsanguination occur within minutes of injury, and survival to hospital arrival occurs in a minority of patients. Those who survive long enough to be diagnosed as having a thoracic aortic injury often have lesser injuries or have developed a pseudoaneurysm contained within the aortic adventitia and mediastinal pleura.

EPIDEMIOLOGY

Blunt aortic injury is second only to head injury as a cause of death following motor vehicle crashes.(3) Other high-energy blunt trauma mechanisms including auto–pedestrian collisions, motorcycle crashes, airplane crashes, falls from significant heights, and sudden thoracoabdominal crush injuries are also associated with blunt aortic injury.(1, 4–6) It is estimated that there are 8,000–9,000 deaths per year in the United States attributable to blunt aortic injury, with 70–80% occurring prior to hospital arrival.(3, 6–9)

The site of injury to the thoracic aorta is variable depending on whether the injury is identified at autopsy or during clinical evaluation. Injuries involving the isthmus represent 70–90% of those described in surgical series while the percentage of those occurring in the ascending aorta increases in autopsy series,

highlighting the greater lethality of more proximal injuries.(1, 3, 6, 10–12) The fact that the proximal descending aorta is the location of injury for most patients who arrive alive at a hospital is explained in part by the additional connective tissue layer offered by the mediastinal pleura in the descending segment which may contain the aortic rupture and allow formation of a false aneurysm. (8) On the other hand, injuries to the ascending aorta may result in tamponade and are more commonly associated with blunt cardiac trauma, both of which significantly increase mortality.(1, 7, 9, 13)

Other locations of blunt aortic injury include the distal descending thoracic aorta and the transverse arch; the former is frequently observed in association with fractures of the thoracic vertebrae. Multiple sites of aortic injury and synchronous arch vessel injuries are identified in a smaller number of patients and are frequently lethal.(3, 4, 6, 9, 14, 15)

Initial descriptions of the injury mechanism responsible for blunt thoracic aortic injury focused on rapid horizontal or vertical deceleration as occurs during a high-speed motor vehicle crash or fall from a significant height.(6, 16, 17) It appears however that this alone may be insufficient to injure the thoracic aorta, at least under the forces commonly observed in motor vehicle crashes. Cadaveric impact models, using a fixed thorax to minimize chest deformation, fail to reproduce thoracic aortic injury even when subjected to forces exceeding 200 times gravity.(18) This highlights the potential importance of other biomechanical factors that occur at the moment of injury including chest wall deformation (as may occur with steering wheel impact) and aortic pressure changes (see below).

While the frontal impact motor vehicle crash is commonly emphasized as a risk factor for blunt thoracic aortic injury, more recent analyses of national crash data sets suggest that side impact crashes may be equally important in producing injuries to the thoracic aorta. This is especially true when there is significant vehicle compartment intrusion impacting the lateral chest wall.(6, 7, 19–22) The incidence of aortic injuries associated with side impact motor vehicle crashes also may be increasing over time. It is not clear, however, if this is due to an increased understanding of crash mechanisms or an actual shifting of the demographics of injury impact due to improvements in vehicle frontal safety mechanisms.(20)

Despite decades of speculation and research, the precise physical forces involved in the generation of a thoracic aortic injury following blunt trauma have not been clarified. As mentioned previously, frontal deceleration alone is unlikely to be responsible for the observed injury pattern and lateral force vectors appear to be important in some cases. Anterior chest wall trauma may result in compression of the aorta between the manubrium and the spine, sometimes known as an "osseous pinch."(5) A sudden rise in intra-aortic pressure due to pinching of the aorta at the diaphragm has also been postulated, as has a "water hammer" effect due to increased pulse wave reflection that can occur after distal aortic occlusion from a similar mechanism. The "Archimedes lever" hypothesis proposes that the ascending aorta and heart act as the long arm of a lever rotating about the left subclavian artery with the aortic isthmus serving as the lever short arm. In a motor vehicle crash with a near side lateral impact to the upper left chest, maximal strain is produced at the aortic isthmus, with sufficient magnitude to cause injury.(7, 23) The different theories regarding the mechanical forces involved

in blunt aortic injury suggest that different mechanisms can occur in different patients or that multiple mechanisms could be active simultaneously in the same patient. Given the predictable location of these injuries, it is plausible that these forces converge to act through a final common pathway that maximizes aortic wall strain at one of several locations.

DIAGNOSIS

Evaluation of a patient with suspected blunt aortic injury begins, as in any trauma patient, with a thorough trauma assessment and a careful search for head, thoracic, abdominal, and extremity injuries. Other life-threatening injuries are common, and their management generally takes priority over evaluating the patient for thoracic aortic injury. Nonetheless, it is critical to identify patients at high risk for aortic injury based upon the mechanism of injury and an initial supine anteroposterior chest radiograph.(24) Chest X-ray findings in patients with blunt thoracic aortic injury include superior mediastinal widening (> 8 cm just above the aortic arch, ratio of superior mediastinal width to chest width greater than 0.25), loss of the aortopulmonary window, tracheal shift to the right, left mainstem bronchus depression, deviation of the nasogastric tube to the right, left apical capping, widening of the right paratracheal stripe, and left-sided pleural effusion (25–27) [Figure 7.1]. None of these findings is either terribly sensitive or specific and a supine chest radiograph may be normal in 10–30% of patients with a blunt aortic injury, even when the aorta is completely disrupted.(27–30) Isolated first rib fractures are not associated with aortic injury in the absence of other physical exam or chest radiographic findings. (31–33) Upright positioning improves the ability of chest radiography to exclude this injury but is frequently impractical during initial blunt trauma evaluation.(25)

Given that undiagnosed aortic injuries are highly lethal, reliance on nonspecific physical findings or chest radiography as a definitive test is potentially hazardous and more extensive evaluation is prudent in those at high risk for aortic injury. Features of the history such as fall height (greater than 15 ft), vehicle speed and type of crash (high vs. low speed, front or side impact), use of restraints, and degree of vehicle damage can give some insight into the risk of aortic or great vessel injury.(19, 28, 34) It should be noted that lower degrees of blunt force may produce aortic injury in elderly patients.(22, 35) The wide availability of CT has simplified screening for blunt aortic injury in high-risk patients (see below).

For many years, catheter aortography was the only available method beyond chest radiography to diagnose injury to the aorta and great vessels.(36) Although time honored as the gold standard, aortography is not without limitations. Access complications, although generally minor, occur in up to 2% of cases. Guidewire and catheter-associated vascular injury have been reported and may be severe.(37, 38) Finally, logistical considerations and procedural cost make it a poor choice for screening.(39)

Over the last several decades, CT technology has advanced to the point where it is used routinely in the evaluation of patients with blunt trauma and its use for the workup of blunt thoracic injury is no exception. Older generation single slice scanners had poor spatial resolution, were time intensive, and produced images that were prone to motion artifact. As a result, they were unable to reliably detect thoracic vascular injuries.(40) Newer
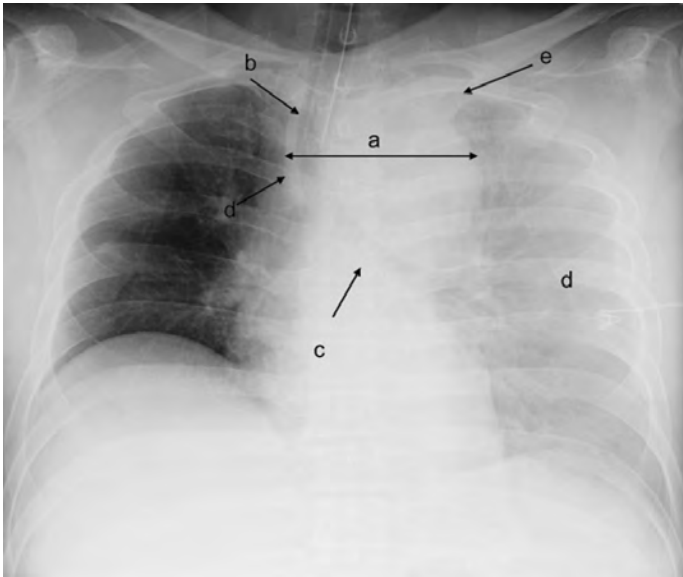
Figure 7.1 Supine anteroposterior chest radiograph of the patient in the case scenario taken within minutes of emergency department arrival. The X-ray illustrates several of the typical findings observed in patients with a blunt thoracic aortic injury. A=widened mediastinum (> 0.25 mediastinum to chest width ratio); b=rightward tracheal deviation; c=depressed left mainstem bronchus; d=enlarged right paratracheal stripe; e=left apical cap; f=left pleural effusion (hemothorax).

multidetector helical scanners, available in most trauma centers, can perform complete imaging of the head, neck, chest, abdomen, and pelvis in several minutes. The rapid scanning produces contrast-enhanced images of the chest that may be equivalent and in some cases superior to catheter angiography with regard to identifying injuries of the thoracic aorta. Advanced computer software allows the rapid creation of multiplanar reconstructions in two and three dimensions. Axial views are often sufficient to characterize an injury to the thoracic aorta and may be useful for aortic sizing for stent graft placement, while multidimensional reconstructions can provide a picture similar to catheter aortography and create images which may be more familiar to the treating surgeon.(41)

The role of CT in the evaluation of blunt aortic injury has evolved steadily over time.(29, 42, 43) Advocates for its liberal use cite 98–100% sensitivity and a negative predictive value approaching 100% in high-risk patients. The reported positive predictive value has been more variable, with rates ranging from 20 to 100% depending on the sophistication of the scanners used, the population studied, and the criteria for positivity (mediastinal hematoma vs. actual pseudoaneurysm).(44–46) Suboptimal contrast injection or motion artifact can compromise image quality, without the real-time adjustments that can be made with catheter aortography. The possibility for missed ascending, arch, and branch vessel injury, which may not be as well visualized using CT, is frequently cited as a reason for routine follow-up catheter angiography, as is the fact that many surgeons are more comfortable planning a therapeutic intervention using catheter angiography images.(40, 46) False-positive exams, most commonly because of the misinterpretation of a ductus diverticulum as a pseudoaneurysm, have been reported; the frequency of false positives is

roughly equal to that of catheter angiography, however.(43, 47) Despite its limitations, dedicated CT aortography can reliably demonstrate direct signs of aortic injury and in many trauma centers is the most common imaging study currently employed after routine chest radiography.(11)

The increasing use of endovascular stent grafting has also changed the role of CT in the initial diagnosis and characterization of blunt thoracic aortic injuries. In centers where blunt aortic injuries are treated using an endovascular approach, diagnosing the injury begins with CT aortography and catheter angiography is done as a matter of routine during the course of stent graft placement.(11, 48) This approach allows the treating surgeon to further image areas of concern or poor image quality such as the proximal aorta and arch vessels immediately prior to treatment. When planning an open surgical approach for repair, some institutions favor routine follow-up of all positive and equivocal CT studies with catheter angiography, while others favor selective angiography done only in equivocal cases.(41, 43, 44, 46, 47)

Transesophageal echocardiography (TEE) is another technique used to identify blunt aortic injury. Reported sensitivity and specificity for injuries of the descending thoracic aorta have been high, with the important caveat that a significant number of the injuries seen are intimal disruptions of questionable clinical significance. (49, 50) TEE is minimally invasive and can be done at the bedside or during operative treatment of other life-threatening injuries. The major disadvantages include limited operator availability and experience. In addition, imaging of the ascending aorta and arch vessels may be obscured by tracheobronchial gas and distance from the ultrasound probe. TEE is most useful in the high-risk patient who requires emergency operation for other reasons (craniotomy, laparotomy) and may be too unstable for transport to radiology for other aortic imaging. Alternatively, it may occasionally be useful as a confirmatory test after an equivocal aortogram.(51)

Magnetic resonance angiography (MRA) and intravascular ultrasound are two additional techniques for the evaluation of the aorta after blunt injury, but both are of limited utility in the acute setting. Magnetic resonance imaging is highly sensitive and specific, but the time required for imaging is prohibitive in the acute management of severely injured patients. In addition, the use of a powerful magnet often poses logistical problems. MRA is a reasonable option in a stable patient when there is a contraindication to the administration of radiocontrast agents. It may also have a role in the follow-up of chronic traumatic aneurysms.(52, 53) Intravascular ultrasound is relatively new and may be useful for determining the significance of subtle abnormalities identified by either catheter or CT aortography. It is not universally available, however, and adds little important clinical information in most patients.

The diagnosis of blunt aortic injury requires a high index of suspicion, as physical findings are often nonspecific. An initial plain chest X-ray should be done and should be followed with a screening contrast CT angiogram if the patient had a high-risk mechanism of injury, has associated injuries suggestive of the possibility of an aortic injury, or if there is any question on chest X-ray about the presence of a mediastinal abnormality. If the CT scanner is of limited sophistication or the images contain significant artifact, the scan should be used to screen for the presence of a mediastinal hematoma, and follow-up catheter aortography

should be done when a mediastinal hematoma is seen on CT. If the scanner is a newer generation scanner capable of providing high-quality CT angiography, the CT scan itself can be used as the definitive diagnostic study or can be followed by catheter angiography, depending on the surgeon's preference. If the CT scan and the patient's overall condition suggest that endovascular stenting is a possibility, catheter angiography should be done as part of the stenting procedure. TEE and intravascular ultrasound are complementary studies that are only occasionally indicated in select circumstances as described above.

> The case patient was involved in a high-speed head on motor vehicle crash which resulted in a significant horizontal deceleration force directed posteriorly. Although the history alone suggests the patient is at increased risk for aortic injury, the chest X-ray demonstrates multiple findings consistent with aortic injury [Figure 7.1]. Contrast-enhanced CT using a multidetector helical CT confirms the presence of an injury at the level of the isthmus [Figure 7.2]. In this case, diagnostic catheter arteriography was used to confirm the injury immediately prior to endovascular stent graft placement.

TREATMENT

Current management of blunt thoracic aortic injury is based on the stability of the patient, the location and severity of the aortic injury, the presence of other severe injuries, and institutional or surgeon experience. Historical data mandated early operative repair, but this was prior to the advent of improved prehospital systems, improved imaging, the routine use of pharmacologic anti-impulse therapy, and changes in open repair techniques. Furthermore, evolution of the management of non-thoracic injuries, including nonoperative management of solid organ injury and the ability to perform open repair without heparinization, has affected treatment priorities. Finally, the introduction of endovascular stent grafts alters the risk to benefit ratio of repair. Taken together, these factors call into question the application of prior management principles, and optimal treatment is currently in evolution.

Initial management is focused on treating other life-threatening injuries. Significant multisystem trauma occurs in approximately 50–70% of patients who present with blunt aortic injury. The most common associated injuries include other thoracic injuries, head injuries, abdominal injuries, and orthopedic injuries.(10, 54, 55) When shock is present during initial patient evaluation, it is uncommonly due to the aortic injury.(54) The original Parmley paper from 1958 that so nicely described the pathologic anatomy of aortic injury, because it was based mostly on fatal cases, placed undue emphasis on the need to address the aortic injury as a very high priority. While other authors have found a similar incidence of early rupture, most, if not all of these were observed prior to the widespread adoption of current pharmacologic management strategies. In a multicenter observational study of level 1 trauma centers published in 1997, 9% (24/274) of blunt aortic injuries ruptured prior to planned thoracotomy, and over 90% of these occurred within 24 h of presentation. Unfortunately, only 17% of the patients in this series received beta blocker and antihypertensive therapy.(10)

In the setting of appropriate pharmacologic therapy, the risk of free aortic rupture appears to be significantly less. Several authors have reported delayed rupture in less than 2% of patients receiving beta blocker and antihypertensive therapy.(56–59) In some cases, definitive therapy can be delayed for days to weeks when necessary. Given that rupture of an aortic pseudoaneurysm is almost uniformly fatal even when it occurs in the hospital, initial efforts should be focused (1) on treatment of other life-threatening injuries and (2) on the identification of blunt thoracic aortic injuries and early institution of medical therapy (see below), in some cases prior to radiographic confirmation.

> The patient sustained multiple injuries including a left pulmonary contusion, left hemothorax, left acetabular, and left femur fracture. Early hypotension that occurred during the course of evaluation was due to blood loss from his associated injuries and not due to a ruptured aortic pseudoaneurysm. This was confirmed by evaluating the chest tube output as well as a repeat chest X-ray which demonstrated a stable appearing mediastinal hematoma. He was immediately resuscitated and responded appropriately.

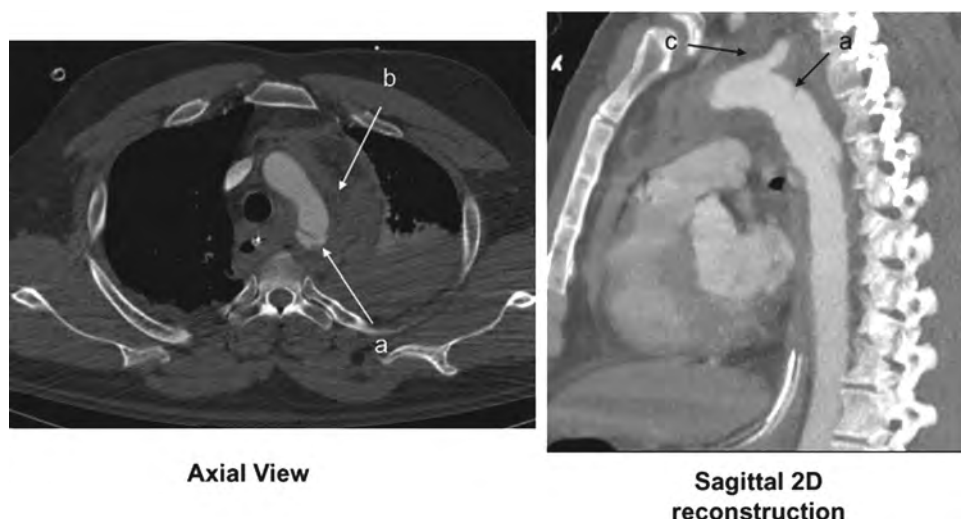**Axial View**

Sagittal 2D reconstruction

Figure 7.2 Axial and sagittal two-dimensional reconstruction demonstrating aortic injury (a) and mediastinal hematoma (b). The origin of the left subclavian artery (c) can be seen in the sagittal view.

MEDICAL MANAGEMENT (BETA BLOCKADE AND AFTERLOAD REDUCTION)

Although some patients who present with blunt thoracic aortic injury require urgent operative repair, a more conservative and complementary approach has evolved over the last several decades. The use of anti-impulse and antihypertensive therapy was reported by Akins and colleagues in 1981 and was prompted by the observation that the risk of rupture during a temporizing delay can be minimized through the use of agents that decrease cardiac ejection pressure (dP/dT) and blood pressure.(60) In addition it was well known that early operative repair was associated with high perioperative mortality in the subset of patients with severe associated injuries, especially when therapeutic anticoagulation was required. The results of Akins and others since then support a role for delayed repair and in some cases, nonoperative treatment as definitive management. Published goals for heart rate and systolic blood pressure are variable but suggest that maintaining a heart rate of less than 90 and a systolic blood pressure of less than 110 mmHg are a reasonable compromise to minimize the risk of rupture while maintaining visceral perfusion, especially in the setting of multisystem trauma.(56, 58, 59, 61) In a young patient with an isolated aortic injury, more aggressive therapy may be justified when repair is delayed. In older patients, a less aggressive approach may be warranted if there is a significant risk of cerebral, cardiac, or other visceral ischemia. Once instituted, medical therapy should continue until aortic repair is undertaken, as even brief interruptions in pharmacologic therapy have been associated with aortic pseudoaneurysm rupture.(59)

Despite the fact that recent advances (heparinless centrifugal pump, endovascular stenting) have made early repair safer and allowed for earlier intervention in some patients with severe associated injuries, the use of anti-impulse and antihypertensive therapy should be employed when possible in all patients awaiting repair, regardless of the time interval involved. Delayed ruptures do occur, usually during the first week after injury, and the risk of delayed rupture when choosing nonoperative management as an initial strategy should be weighed against the risks of early intervention.(57, 62)

Primary nonoperative management may be suitable for small intimal injuries or in patients in whom severe associated injuries dictate prolonged expectant observation. In these patients, beta blocker and antihypertensive agents should be administered with the aforementioned goals. While the optimal duration of therapy is unknown, it has been suggested that the target blood pressure can be liberalized after 1 week.(56) In practice, the goals and duration of pharmacologic therapy should be dictated by the condition of the patient, the severity of the aortic injury, and the results of follow-up imaging.

Patients managed nonoperatively who have anything more than trivial intimal injuries should be followed with CT aortography or MRA until the reason for delay has resolved. In some cases, the aortic injury may resolve on its own. Alternatively, a chronic traumatic pseudoaneurysm may develop. Such chronic pseudoaneurysms can be stable for years, although many will eventually produce symptoms, sometimes related to compression of surrounding structures. In high-risk patients, expectant management is reasonable with a more aggressive approach when the pseudoaneurysm is symptomatic or there is evidence of expansion.(63)

Beta blocker and nitroprusside therapy were started as soon as the thoracic aortic injury was diagnosed (following resolution of hypotension), in order to prevent pseudoaneurysm rupture. This allowed stabilization of his pulmonary function and a more thorough assessment and treatment of his nonaortic injuries while definitive therapy was planned.

TIMING OF REPAIR

Patients who are suspected on the basis of imaging studies to have a blunt aortic injury and who suffer sudden arrest should undergo emergency operative intervention, although even after admission to the hospital such rupture is commonly fatal. Evidence of "pending" rupture may be occasionally seen and includes findings such as increasing chest tube output or progressive mediastinal widening on chest radiograph. Patients who have these findings should also undergo urgent operative exploration. In centers where stent grafting is commonly performed, angiography in the operating room with stent graft placement can sometimes be done on an emergent basis. This allows emergent open repair if the patient turns out not to be a candidate for an endovascular approach. In stable patients, the nature of other injuries should be fully characterized when time permits. In particular, the presence of intracranial hemorrhage is important because it is a relative contraindication to systemic anticoagulation. The introduction of heparinless partial bypass circuits for open repair and the advent of endovascular stenting have decreased the need to delay repair in this setting. In addition, early repair in such patients may allow for more aggressive management of cerebral perfusion pressure.(15)

The presence of significant lung injury may make single lung ventilation dangerous and predispose the patient to postoperative acute respiratory distress syndrome.(54) Currently, delayed repair should be considered in the setting of significant brain or pulmonary injury or if there is ongoing hemorrhage from another location that necessitates more urgent attention (abdomen, pelvis, or extremity). In addition, older patients with significant cardiopulmonary disease may benefit from a delayed approach, in order to minimize the risks associated with emergency thoracotomy.(64) Injuries such as extensive burns or significant enteric contamination have been hypothesized to increase the risk of graft infection and have also been invoked as potential reasons for delay in intervention, although the risk from these conditions is likely more theoretical than real.

OPERATIVE REPAIR

The approach to open repair depends on the urgency and/or presence of associated injuries. Although adequate exposure can be obtained through a fourth interspace left anterolateral thoracotomy, a fourth interspace posterolateral thoracotomy is preferred if the patient's condition permits. The advantage of the anterolateral thoracotomy is simultaneous access to the abdomen and groins that facilitates treatment of abdominal visceral injuries as well as ease of bypass. Posterolateral thoracotomy provides better exposure to the proximal descending aorta and is preferred when an open repair is undertaken. If access to the abdomen or groins is

needed for abdominal exploration or placement of femoral cannulae for bypass, the chest can be placed in the lateral decubitus position and the hips swiveled to allow the abdomen and groins (particularly the left groin) to be in the operative field. Placement of a double lumen endotracheal tube and single lung ventilation facilitates exposure but is not absolutely necessary if time, expertise, and patient condition do not permit.

Proximal aortic injuries, including those to the ascending or arch region, generally require operative intervention including cardiopulmonary bypass or hypothermic circulatory arrest. Injuries at the isthmus can be repaired directly using a "clamp-and-sew" approach. Alternatively, there are several methods of distal aortic perfusion available, many of which require at least some heparin (see below). Use of a synthetic interposition graft is usually necessary due to the frequency of complete transection and the desire to avoid tension on the repair, but simple repair may be appropriate for some partial circumferential injuries.

For injuries at the most common location just distal to the takeoff of the left subclavian artery, initial control should be directed to the distal thoracic aorta well removed from the site of injury. Control can then be advanced more proximally after control of the other vessels has been achieved and will minimize cord ischemia during cross clamping. Distal dissection should be limited as much as possible to avoid injury to posterior segmental branches supplying the spinal cord. The left subclavian should be controlled after the distal aorta, again far enough away from the site of injury to minimize the risk of entering the pseudoaneurysm. The aorta proximal to the injury should be approached only after control of the distal aorta and subclavian artery has been obtained. This is the most difficult part of vascular control and is the part of exposure most likely to result in pseudoaneurysm rupture. During dissection of the proximal aorta, the adjacent pulmonary artery can be avoided by staying on the aortic surface. During dissection of both the subclavian artery and the proximal aorta, the left recurrent laryngeal nerve should be identified and protected if possible, although the control of hemorrhage always remains a higher priority. The proximal aortic clamp may be placed immediately distal to the left subclavian artery but the aortic cuff distal to the subclavian artery is often too short to allow easy clamp placement at that location and more proximal placement, between the left common carotid and left subclavian artery, is often easier. Repair is then effected either primarily or with a short segment of appropriately sized Dacron graft using standard vascular technique.

Complications of open operative repair include bleeding, paraplegia (either early or delayed), renal failure, and recurrent laryngeal nerve injury with resultant vocal cord paresis.(10, 58) Intraoperative blood loss is minimized by ensuring early vascular control. Postoperative bleeding is uncommon although, as is the case with any vascular reconstruction, anastomotic dehiscence can occur. In most cases, anastomotic dehiscence occurs on a delayed basis with pseudoaneurysm formation and, in some cases, is associated with graft infection. Paraplegia is not completely predictable but seems to be related to aortic cross-clamp time and possibly to the adequacy of distal perfusion (see below).

DISTAL AORTIC PERFUSION

Surgeons have debated for several decades the need for distal aortic perfusion to minimize the risk of paraplegia. The "clamp-and-sew"

technique has been advocated by some, in particular when surgeons experienced with this injury and technique are available.(65–67) The use of an intraluminal heparin bonded shunt (Gott shunt) has been used by some centers as a way to maintain distal aortic perfusion without systemic heparinization.(68, 69) Limitations of intraluminal shunting include the inability to monitor distal aortic perfusion pressure and the possible exclusion of critical segmental branches in the region of distal shunt insertion. The limited published data using this technique suggest that paraplegia rates are similar when compared to direct repair ("clamp and sew") and seem to be primarily related to total aortic cross-clamp time.(70)

Partial and complete cardiopulmonary bypass techniques have the theoretical advantage of maintaining spinal and visceral perfusion during aortic repair and thereby minimizing the risk of ischemia when aortic clamp times exceed 30 minutes. They also theoretically offload the proximal circulation enough to minimize increases in cerebrospinal fluid pressure and thus help maintain blood flow to the spinal cord. The ability to maintain spinal cord and visceral perfusion using a continuously monitored pressure circuit should decrease the risk of spinal cord ischemia. In addition, maintenance of mesenteric, renal, and lower extremity perfusion may limit reperfusion inflammatory response and minimize the risk of postoperative renal dysfunction.(71) Finally, bypass allows repair without the time constraints of direct repair and therefore may be more suitable for lower volume centers.

Early results using variations in cardiopulmonary bypass were plagued by bleeding complications in trauma patients due to the need for systemic heparinization. The use of bypass with a heparinless centrifugal pump is an attractive alternative to "clamp and sew."(72, 73) Although there have been no randomized trials to date, several studies suggest that paraplegia rates are lower with bypass and are directly related to cross-clamp times greater that 30 minutes when bypass is not used.(10, 70, 74–76) Evidence over approximately the last decade has tipped conventional wisdom more and more toward the use of bypass during open repair when possible.(14, 76, 77)

ENDOVASCULAR STENTING

Endovascular stent grafts for the thoracic aorta have been available for over a decade, and their use in the management of aneurysmal disease is well supported in appropriately selected patients.(78–81) The minimally invasive nature of the endovascular approach and the ability to forego systemic anticoagulation make endovascular repair a particularly attractive approach in trauma patients, especially those with severe brain or pulmonary injury.

The use endovascular stent grafts for blunt aortic injury has increased significantly over the last several years and is now the most common treatment method employed.(11) First reported in 1997, stenting was initially considered an alternative to open repair in high-risk patients, particularly the elderly and those with significant multisystem injury.(82) Initial reports suggested that endovascular devices could be safely employed with few short-term complications and subsequent experience demonstrated low morbidity rates.(83, 84) The success of the endovascular approach and the initial low complication rates in traumatic aortic injuries are particularly impressive given that the available devices are designed for use in thoracic and abdominal aneurysmal disease

and therefore not ideal for younger trauma patients with smaller aortic diameters. The lack of appropriately sized endografts for use in trauma patients precludes their use in some cases where there is simply no graft that will fit appropriately in the patient's aorta.

Complications of endovascular stent graft placement include stent migration, endoleak, stroke, complications related to vascular access, and graft infection.(11, 84–86) Due to the size of the graft, common femoral artery cutdown is frequently required for initial access or vascular closure. Iliac artery access may be required due to the length of the delivery system when using devices designed for treatment of abdominal aortic aneurysms. Coverage of the left subclavian artery is sometimes necessary; fortunately the consequences are generally minimal. Some surgeons have advocated routine carotid-subclavian bypass if proximal graft placement requires occluding the origin of the left subclavian artery. With increasing experience, it has become apparent that such bypass grafting is unnecessary in most cases.(87–90) Stent collapse and aortic thrombosis have been observed, sometimes related to a size discrepancy between the stent graft and native aorta. "Lipping" of the endograft along the inferior aspect of its proximal edge, exacerbated by size discrepancy and the curvature of the aorta at that location, can give rise to both endoleak and collapse of the graft. Given the young age of many trauma victims and changes that occur in the thoracic aortic contour with time, it is conceivable that there will be a need for subsequent intervention in trauma patients with endovascular aortic devices, although experience to date has not highlighted this as a common phenomenon. While the long-term outcome of endovascular stenting for blunt aortic injury is currently unknown, the extremely low peri-procedural morbidity and mortality suggests that the use of these devices will continue to increase. Short-term complications as well as the concern for long-term problems may diminish as stents designed for a younger trauma patient population become available.

> The patient's associated injuries would make lateral decubitus positioning and single lung ventilation difficult during open repair. In this case, the patient was treated using an endovascular stent graft [Figure 7.3]. Early experience suggests a low morbidity and mortality associated with this treatment. If open repair were chosen, techniques to maintain distal perfusion should generally be employed. Although anticoagulation in the setting of a low-grade splenic laceration may be safe, atriofemoral bypass can be performed without heparin and is the preferred method in some centers.(91)

MINIMAL AORTIC INJURIES

As imaging capabilities have become more sophisticated, smaller degrees of aortic injury have been diagnosed. In particular, isolated intimal flaps of the aorta are sometimes seen on CT angiography, magnetic resonance aortography, TEE, and intravascular ultrasound. When the flap is small and there is no evidence on good quality imaging studies of full thickness injury to the aortic wall, these lesions should be treated expectantly with medical management (beta blockade and blood pressure control) and follow up imaging until the lesion resolves.(2, 92–94)
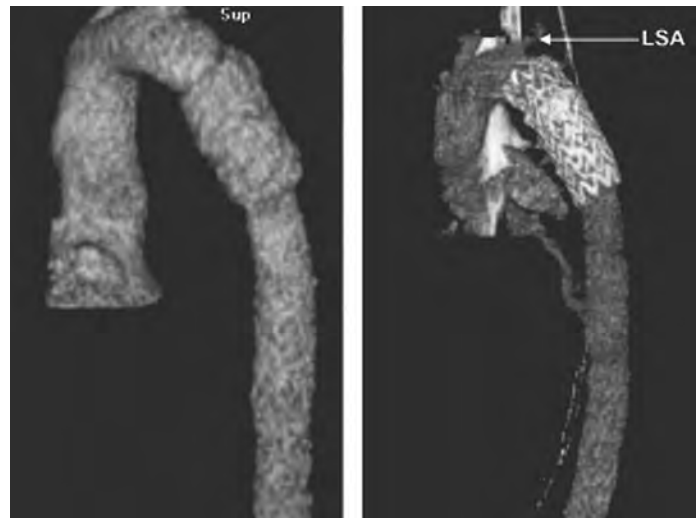

Figure 7.3 Three-dimensional reconstructions demonstrating the aortic pseudo-aneurysm (A) and the aorta after stent graft placement (B). LSA=left subclavian artery.

OUTCOME

Outcome following blunt thoracic aortic injury is related largely to the severity of associated injuries. For most patients who arrive at the hospital alive, rapid diagnosis allows the institution of pharmacologic therapy to minimize the risk of early rupture while definitive treatment is planned. Pharmacologic therapy has also proven to be definitive in selected patients with a low risk of subsequent aortic rupture. When open repair is undertaken, use of bypass techniques to maintain distal aortic perfusion appears to decrease the risk of postoperative paraplegia. Endovascular stent grafts further minimize the procedural risks associated with repair and have significantly altered the management of blunt aortic injury. Early mortality in patients treated with stent grafts is comparable and possibly better than that observed with open surgery, and the incidence of paraplegia is near zero. As with open surgery, death is most often due to associated injuries.(11) A summary of evidence-based recommendations is presented in Table 7.1.(95)

Long-term outcomes following stent graft placement are unknown. Currently, results of long-term follow-up are limited to 3–5 years in most series with the longest being approximately 9 years.(85, 96–99) Given the relatively young age of the trauma population, the rate of late device failure due to stent material deterioration, stent migration, or as a result of increasing aortic diameter needs to be determined. At this time, close follow-up with serial imaging is recommended. A reasonable approach is repeat CT aortography at 1 week, 1 month, 6 months, and 1 year with yearly imaging thereafter, at least until the long-term durability of these devices is established.

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Table 7.1 Evidenced Based Recommendations for the Diagnosis and Treatment of Blunt Thoracic Aortic Injuries.

Issue	Finding	Grade of Recommendation
Screening radiography: chest radiography vs. computerized tomography	Supine chest radiograph has an unacceptable false negative rate in high risk patients[*]. Helical CT can reliably exclude aortic injury when dedicated CT aortography is done and the aorta is well delineated. When the aorta is poorly visualized, identification of a mediastinal hematoma requires further evaluation (catheter or CT aortography). The proximal aorta and great vessels should be well visualized in order to exclude these, less common injuries	1A
Definitive imaging: Multidetector helical CT vs. diagnostic catheter angiography	Multidector helical CT is adequate when satisfactory axial images and multiplanar reconstructions are available as determined by the treating surgeon	1C
Anti-impulse pharmacologic therapy	Should be started when the injury is suspected and continued until operative vascular control is obtained. Short acting beta blocker therapy (e.g., esmolol) should be first line therapy and titrated to a heart rate of less than 90 bpm[†]. Additional short acting vasodilator agents (e.g., sodium nitroprusside) should be added to keep the systolic blood pressure less than 110 mm Hg[2]. Invasive monitoring is recommended during treatment	1C
Timing of repair (open): early vs. delayed	Delayed repair is preferred if necessary to allow stabilization of other life threatening injuries. Patients with severe traumatic brain injury requiring intracranial and cerebral perfusion pressure (CPP) monitoring may benefit from earlier repair to allow for more aggressive CPP management	1C
Timing of repair (endovascular): early vs. delayed	Delayed repair may be preferable to allow full characterization of other injuries or if vigorous resuscitation is ongoing. Lower peri-procedural complications suggest that early endovascular repair may be safe in select patients	2C
Technique of Open Repair: "Clamp and Sew" vs. the use of active distal aortic perfusion	Use of partial bypass decreases the risk of paraplegia when compared to "clamp and sew". Systemic anticoagulation should be avoided in the multiply injured patient. May not apply to high volume centers with experienced aortic surgeon available. Ascending aortic and arch injuries generally require complete CPB or hypothermic circulatory arrest	2B
Type of repair: endovascular vs. open	Endovascular is preferred in the setting of multiple injuries or when significant comorbid conditions are present. Endovascular repair has a significantly lower peri-procedural morbidity, including a near zero rate of paraplegia. The long term outcome is unknown, especially in the young trauma patient. Open repair may be preferable in a young patient with an isolated thoracic aortic injury	1C

[*] These include trauma secondary to a rapid horizontal or vertical deceleration mechanism. Lower degrees of force may produce thoracic aortic injury in elderly patients.
[†] Published goals for heart rate and blood pressure are variable and therefore higher or lower values may be appropriate in select patients (see text).

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8 Transmediastinal penetrating trauma
Kevin Schuster and Erik Barquist

A 32-year-old man was shot with a small caliber pistol during an altercation. He is brought to the trauma center with stable vital signs. He is awake and alert. There is no stridor or other signs of airway compromise. Breath sounds are reduced in the left chest and the oxygen saturation via pulse oximetry is 90% on room air. Blood pressure is 130/85 and pulse rate is 105. Secondary Survey reveals a small left infraclavicular gunshot wound and no exit wound. The remainder of the physical examination is normal.

A chest tube is placed in the fourth intercostal space at the midaxillary line on the left. There is a gush of air but no blood is immediately expressed. There is no persistent air leak and no fluid is removed when the chest tube is placed to suction. A chest X-ray (CXR) shows a well-positioned chest tube, a fully expanded left lung, and a right apical pneumothorax with no hemothorax. The bullet fragment is found to be near the midportion of the right scapula. There appears to be a small fracture of the scapula consistent with passage of the bullet. A chest tube is placed in the fourth intercostal space at the midaxillary line on the right with a small amount of air drained. The patient remains stable and is then sent to the computed tomography (CT) scanner for further radiologic workup.

WHY IS THE WORKUP OF PENETRATING TRAUMA TO THE MEDIASTINUM COMPLEX IN STABLE PATIENTS?

Injury to the lower neck and upper chest remains one of the most difficult areas in acute trauma care. This portion of the body contains elements of the aerodigestive tract, the great vessels, important peripheral nerves, as well as the spinal column. An injury to any of these structures can prove devastating, both in the short term because of immediate life threat and in the long term because of permanent disabilities. If the patient presents with unstable vital signs, usually due to hemorrhagic shock, immediate operation is indicated. The choice of incision may be complicated and dependent to a certain extent on the preference of the operating surgeon, but the need for open exploration and repair of injured vessels and organs is unquestioned. Later disabilities due to chronic pain syndromes associated with thoracotomies and so called "trap door" incisions are accepted as a consequence of the immediate life threat. This is not the case with those patients that present with no immediately obvious reason for open surgery. In these cases, a rapid workup must be performed to rule out occult injury to mediastinal structures, but the incisions can be planned or perhaps completely avoided in some cases.

Assessment of the airway and breathing along with a complete physical examination precedes the radiologic and endoscopic workup of these injured patients. Abnormalities are immediately addressed as needed. For the purposes of this discussion it is presumed that vital signs (breathing and circulation) remain intact during the assessment of these patients. Any deterioration in the hemodynamic status demands immediate attention and usually operation.

The first radiographic test ordered is the plain CXR. This study may detect subtle pneumothorax, hemothorax, or pneumomediastinum. Blood, fluid, or air in the thoracic cavity should be evacuated with a chest tube inserted in the midaxillary line. A visual examination of any fluid removed may differentiate between blood and content from the gastrointestinal tract. Massive air leak or failure of the injured lung to reexpand may indicate a need for operation as does ongoing bleeding from the chest tube. In most centers, the second radiologic test performed is a CT angiogram either with or without three-dimensional reconstructions. The older literature suggests that an angiogram should be performed prior to any other radiologic investigation. In many centers, however, a CT is obtained quickly at night, while an arteriogram may take up to an hour for team arrival and room setup. Many interventional radiologists feel that the information gained from a screening CT scan allows them to direct their interventions and limits IV contrast loads administered to the patient.(1) In some cases, the CT scan also allows identification of the tract of the penetrating object, limiting the need for later endoscopic studies. In the rare case of "bullet embolization", the CT may be helpful in determining the final resting place of the bullet or its fragments. If an arteriogram is performed first, and an injury requiring operation is needed, endoscopy is routinely used to clear the aerodigestive tract in the operating room after the arterial or venous injury is repaired if the tract of the penetrating object is not entirely clear to the operating surgeon.(2)

As the presented patient was hemodynamically stable, he is taken to the CT scanner. A chest CT scan shows left apical lung contusion with no pneumo- or hemothorax. The right lung appears normal and fully expanded. The ascending and descending aorta, as well as the other great vessels is well visualized and there is no evidence of injury or proximate trajectory. There is no pericardial effusion. There is trace amount of air around the trachea and esophagus. The bullet is located in the subcutaneous layer above the scapula that is fractured.

DIAGNOSIS AND MANAGEMENT OF CARDIAC INJURIES IN STABLE PATIENTS WITH TRANSMEDIASTINAL GUNSHOT WOUNDS

Most patients who sustain a penetrating injury to the heart die due to pericardial tamponade or exsanguinating hemorrhage prior to arrival at the hospital.(3) Of those patients who arrive alive with normal vital signs and a penetrating injury pattern that may involve the heart, rapid evaluation and treatment are

essential. The initial test to rule out cardiac injury after a transmediastinal gunshot wound is the Focused Abdominal Sonography in Trauma (FAST) exam.(4) The most important element of the FAST exam after transmediastinal gunshot wound is the pericardial view obtained in the subxiphoid location. The subcostal sagittal or longitudinal axis views are generally obtained. An ultrasonographic view of the pericardium can also be obtained from the left parasternal location which is often necessary based on the body habitus of the patient. Reported sensitivity, specificity, and accuracy are as high as 100%, 96.7%, and 97%, respectively.(5) With significant pericardial disruption, blood may accumulate in the pleural space which may also be detected by ultrasound (US). The accuracy of US for the detection of hemothorax has ranged 81–100% sensitive with 100% specificity.(6–8) In the absence of US subxiphoid pericardial window accurately identifies cardiac injury.(9)

When fluid is present in the pericardium by US and the patient has any degree of hemodynamic compromise, immediate exploration through either a median sternotomy or anterolateral throracotomy is indicated. The choice of incision will be based on the suspicion for other intrathoracic injuries. For patients who are otherwise stable there are several options. If the initial US is positive, patients should be taken immediately to the operating room for subxiphoid pericardial window. For patients with possible concomitant intra-abdominal hollow viscous injury, a left parasternal pericardial window is an option to prevent contamination of the pericardium from the abdomen. A thoracoscopic approach for pericardial window has also been described. Morales and colleagues reported on 108 patients who underwent thoracoscopic pericardial window for injuries in proximity to the heart.(10) Thirty-three of these patients had a cardiac injury all of which were successfully repaired. The advantage of thoracoscopy is the potential to evaluate concomitant intrathoracic injury. If the initial study is indeterminate, a complete echocardiographic evaluation can be obtained if this service is immediately available. Another option for the detection of pericardial fluid is CT scanning. CT scanning offers the advantage of identifying other thoracic injuries, the tract of the missile, and therefore the other potential injuries and findings such as pleural fluid that may masquerade as pericardial fluid.(11)

Based on the reports of several other authors, the absence of fluid on US does not rule out cardiac injury.(12, 13) Repeat evaluation with US has been reported but is not currently the accepted standard of care.(5) Patients who develop hemodynamic instability during evaluation and are a risk for cardiac injury should be taken for immediate subxiphoid pericardial window.

If the initial CT scan shows fluid around the heart, a subxiphoid window is required. If blood is found, then median sternotomy is performed for a complete evaluation of the heart. If the CT shows no fluid around the heart, a more sensitive test such as echocardiography or (FAST) may be used to detect pericardial fluid. If either examination is used and shows pericardial fluid, then a subxiphoid window is usually performed, followed by sternotomy as needed.

DIAGNOSIS AND MANAGEMENT OF GREAT VESSEL INJURIES IN STABLE PATIENTS WITH TRANSMEDIASTINAL GUNSHOT WOUNDS

Hemodynamically stable patients who sustain great vessel injuries as a consequence of transmediastinal gunshot wound are quite rare. In one series from Memphis of 77 patients who arrived alive to the trauma center 61% were hemodynamically unstable.(14) For aortic injury specifically, this figure is even higher as another series reported 73% of thoracic aortic injuries arrived to the hospital without a blood pressure, 77% required emergency department thoracotomy, and only 7% survived.(15) In another series from the same institution the incidence of aortic injury in gunshot wound to the chest was also quite low at 1%.(16) This is not surprising as most patients probably succumb to their injury prior to hospital arrival. Of the only two cases of aortic injury stable enough to undergo aortography, one had a pseudoaneurysm and one was missed but eventually developed an aortoesophageal fistula.(16) Other series have reported better results with mortality ranging 33–61% in patients arriving to the operating room alive.(14, 17)

CT angiography (CTA) has demonstrated high degrees of sensitivity and specificity for injuries to both vascular and aerodigestive structures in penetrating neck trauma.(13, 19) Similar series of transmediastinal gunshot wounds that evaluate sensitivity and specificity of CTA through direct comparison with angiography have not been reported. Several reports in the literature have identified CTA as an option to exclude injury if the missile tract can be identified as away from vital structures.(20–22) CTA is followed by biplanar arteriography if major arterial structures demonstrate evidence of injury or are deemed to be at risk based on missile tract.

Of the hemodynamically stable patients from the Memphis series, 32 of 36 underwent diagnostic arteriography. Of those that underwent operative repair without preoperative angiography, the initial incision was considered suboptimal and required supplementation with sternotomy.(14) It is therefore considered essential by most authors to have preoperative angiography prior to attempts at repair. Innominate artery repairs can be generally be completed without cardiopulmonary bypass and with or without shunt placement. The mortality from this injury in modern series has ranged 0–6%.(17, 23) These injuries are generally approached through a median sternotomy and most series have reported no neurologic sequela.(14, 17, 23)

Injuries to the common carotid arteries at their origins are also managed through median sternotomy with neck or supraclavicular extension as necessary. It had been reported in the past that reconstruction of these injuries risked massive cerebral infarction.(24) Most modern authors have recommended direct repair or prosthetic interposition graft. Shunts are rarely used, and neurologic outcomes have been good.(14) Temporary shunts are an option when damage control techniques are being applied for delayed return to the operating room for definitive repair.(25)

Proximal subclavian artery injuries are approached through sternotomy on the right and high (third interspace) anterolateral thoracotomy on the left. These incisions can be supplemented with supraclavicular extension on the right or a separate supraclavicular incision on the left. If access for distal control is difficult, supraclavicular incisions may be supplemented with either division of the clavicle or removal of the midportion. If possible clavicular resections should be replaced and secured with orthopedic hardware to prevent significant functional loss at the shoulder.

Endovascular repair of penetrating traumatic wounds of the great vessels have been sporadically reported. The inclusion of large numbers of iatrogenic injuries in these few series limits their applicability to noniatrogenic injuries.(26) For the present time endovascular repair should be considered based on circumstances surrounding individual patients and availability of local expertise.

Venous injuries detected during workup of a transmediastinal wound can be safely observed if there is no expanding hematoma or active extravasation.(18) All venous injuries requiring intervention may be primarily repaired or ligated if necessary. The exception to this rule is the vena cava which should be primarily repaired or replaced with a prosthetic graft.

If the initial studies indicate that major vascular injury is not present, what studies are done next?

Once major vascular injury is ruled out, a contrast swallow is usually entertained if the patient is awake and alert and able to follow commands. Gastrografin (diatrizoate meglumine) is usually given to the patient first since extravasation into the mediastinum does not cause further injury. If the study is inconclusive, or if further esophagoscopy is not to be entertained, then barium sulfate can be administered. Barium allows better visualization of the esophagus but when spilled into the mediastinum may cause severe inflammation. Some authors have reported a sensitivity of up to 100% for the diagnosis of thoracic esophageal injury with contrast studies alone.(27) In most centers, however, flexible endoscopy is also used as an adjunct study to visualize the esophageal mucosa. Rigid esophagoscopy has fallen out of favor since the optics are poor, general anesthesia is required, and the cervical spine must be cleared prior to the study. Since cervical spine clearance requires imaging and a physical examination without distracting injury being present, many patients are not available for this study. Flexible endoscopy is usually readily available and allows good visualization of the thoracic esophagus. While flexible endoscopy is frequently performed in the operating room at night, due to nonavailability of endoscopy suites at these hours, it does not necessarily require general anesthesia. Flexible bronchoscopy is frequently performed in these cases. This is also generally performed in the operating room. Since most trauma patients are not fasted at the time of their injury, endotracheal intubation is provided to prevent aspiration pneumonia if gastric regurgitation occurs. Intubation can be performed in the patient with an incompletely assessed cervical spine and may be done either under direct vision or via an intubating bronchoscope. This scope may itself be sufficient to rule out bronchial injury.

DIAGNOSIS AND MANAGEMENT OF AERODIGESTIVE INJURIES IN STABLE PATIENTS WITH TRANSMEDIASTINAL GUNSHOT WOUNDS

In general, all esophageal perforations require operative repair. If the esophageal injury is isolated and the patient remains stable, an experienced thoracoscopic surgeon may consider this approach. Most esophageal injuries in the chest require repair via a thoracotomy. If the injury is distal, a left thoracotomy provides the best exposure. While a right thoracotomy is not usually performed in

trauma patients, it may provide good exposure to the esophagus when it is injured in the midthorax. Esophageal repairs are performed with a running absorbable suture and buttressed with a pleural flap. Some authors advocate esophagectomy and later reconstruction with a gastric interposition, but this is a minority viewpoint.

Bronchial injuries may be nonoperatively managed if they involve less than one-third of the circumference of the injured bronchus, the tissues remain in apposition, the patient is not expected to require prolonged positive pressure ventilation, and there is no nearby associated injury. These nonoperatively managed patients need follow-up bronchoscopy to assess the healing and to treat endobronchial granulomas if they occur. Those that are operatively repaired require thoracotomy on the side of the injury, resection of damaged tissues, suture with running absorbable suture, and a pleural flap buttress to the repair.

> The chest CT scan of the presented patient shows mediastinal air. It is unclear if this trace amount of air is secondary to the initial penetrating trauma or to an aerodigestive mediastinal injury. For this reason a Gastrografin swallow is obtained with both anterior–posterior and lateral views. This study shows no traumatic injury. The patient is then taken to the operating room where fiberoptic esophagoscopy and bronchoscopy are performed. This shows a small tangential injury to the left mainstem bronchus. The patient is successfully intubated distal to the injury. He is admitted to the intensive care unit for ventilation and sedation. He is extubated 48 h later after repeat fiberoptic examination showed that the small leak had partially sealed. The right and left chest tubes are removed 3 and 7 days after insertion, respectively. His eventual recovery is uncomplicated.

APPROACH TO MISSED INJURIES

Missed injuries are usually diagnosed because they cause a complication in the patient's recovery period. If these injuries are found within the first 24–48 h they can usually be repaired via methods used when they are diagnosed in a more timely fashion. If the diagnosis occurs later than this, then salvage procedures are needed. In the case of bronchial injury, this involves pulmonary atelectasis due to bronchial obstruction. The proposed operation must address the missed bronchial injury, but must also consider pulmonary resection if the distal segments of lung are either consolidated or chronically infected.(28) Preoperative bronchoscopy with cultures may allow treatment of chronically infected pulmonary segments, limiting the need for pulmonary resection. Depending on the amount of lung involved, and the resulting intrapulmonary shunt caused by slow expansion of collapsed segments, postoperative positive pressure ventilation may be required.

Missed injuries of the esophagus usually present in early convalescence as a mediastinitis. These patients may need esophageal diversion and placement of gastric feeding tubes, since immediate repair or immediate esophagectomy is complicated

in these infected fields. Irrigation and drainage of the mediastinum is combined with antibiotic therapy until the patient is fit for definitive procedure. This may require esophageal diversion for as long as 6 months prior to definitive procedure. Eventual esophagectomy may be needed at the time of definitive repair.(29)

DIAGNOSIS AND MANAGEMENT OF LUNG INJURIES IN STABLE PATIENTS WITH TRANSMEDIASTINAL GUNSHOT WOUNDS

Patients with transmediastinal gunshot wounds will commonly have injuries to one or both hemithoraces also. For all patients presenting with penetrating chest trauma the incidence of lung injury is as high as 88–97%.(30) The diagnosis and management of chest injuries outside of the mediastinum is generally straightforward and rarely requires operative intervention. Many of these patients present with pneumothorax or hemothorax requiring tube thoracostomy but up to 62% are asymptomatic and require no intervention.(31) Small pneumothoraces and other occult findings are present in few patients who sustain penetrating chest trauma, are hemodynamically stable, and have a negative CXR.(32) Several options have been put forward as safe management strategies for these patients with stable hemodynamics and a normal CXR including: 6-h repeat CXR, 3-h repeat CXR, and immediate noncontrast CT scan of the chest.(30, 32, 33)

Hemothorax is a common finding after penetrating chest trauma but the indications for tube thoracostomy remain unclear. Some authors advocate for watching small hemothoraces below the angle of the seventh rib on an upright CXR in an asymptomatic patient.(34, 35) Patients with on occult hemothorax, seen only on CT scan, can be managed safely without chest drainage.(36) All stable patients with a moderate to large hemothorax will require tube thoracostomy. Patients who fail to resolve their hemothorax may require thracoscopic drainage in a delayed fashion 2–7 days after injury.(37, 38) Massive hemothorax, commonly defined as greater than 1.5 l of blood drained from a tube thoracostomy upon initial placement, and continuous drainage of 200–300 ml/h are considered indications for immediate surgical exploration.

Pneumothorax is generally managed with tube thoracostomy drainage when the patient is symptomatic or has pneumothorax detected by CXR. Although there is a paucity of data for management of occult pneumothorax in the penetrating trauma patient, one small series found no negative outcomes when these were managed expectantly.(32) Pulmonary contusion is a common finding after penetrating thoracic injuries and is more commonly identified on CT scan than CXR.(39, 40) If no complications of pulmonary contusion, such as pneumonia, develop, these can be managed expectantly and without radiologic follow-up as all resolve within 14 days.(41) Pulmonary lacerations are also common after penetrating chest injury.(40) Lacerations to the lung can also be managed expectantly. Only those with a persistent air leak after chest tube placement may require delayed operative intervention.

Management of transmediastinal injuries in the unstable patient

The initial management of any patient requires attention to control of the airway, breathing, and circulation. In the case of the patient with transmediastinal injury, this would include emergent intubation, placement of chest tubes for known or suspected pneumothorax, and a fluid challenge. Unless there is immediate response to these maneuvers, the hemodynamically unstable patient requires immediate operation. In some settings, advanced angiographic capabilities may be available in an operating room setting, but the primary approach remains surgical. Resuscitative thoracotomy is useful in limited circumstances such as witnessed arrest in the ambulance or emergency department. In the sole prospective study of this topic a survival rate of 3% was reported. (42) All of these survivors had isolated penetrating cardiac injuries. The choice of incision is frequently a left anterolateral thoracotomy with possible sternal extension, also known as the clam shell incision. If there is no suspicion of pulmonary injury, a median sternotomy may sometimes be used, but this incision leaves little exposure of the pulmonary hila or parenchyma.(43)

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Workup and management of penetrating trauma to the mediastinum	Evidence level	References
Endoscopy can be sued in the operating room to assess the aerodigestive tract	1B	2
The initial test to rule out cardiac injury after transmediastinal gunshot wound is the FAST exam	1B	4
Ultrasound can be used to detect hemothorax	1B	6, 7, 8
Subxiphoid pericardial window accurately identifies penetrating cardiac injury	1B	9
Thracoscopic pericardial window is a safe option for the diagnosis of hemopericardium	2C	10
CT scanning is a safe option in stable patients with possible penetrating cardiac injury	2C	11
CT angiography can be used to exclude injury major thoracic vascular structures if the bullet tract is away from major vessels	2C	20, 21, 22
Endovascular repair of major vascular injuries is an option provided adequate technical expertise is available	2C	26
Major thoracic venous injuries in stable patients without expanding hematoma or active extravasation on arteriography may be safely observed	2C	18
Occult pneumothorax and hemothorax may be safely observed without thoracostomy drainage regardless of the need for positive pressure ventilation	2B	32, 34, 36
Thoracotomy is indicated for patients draining over 1.5 l of blood initially after tube thoracostomy or with 200 cc/h for four or more hours.	1C	30
Choice of incision for emergent cases is left throracotomy	2C	43

9 Diaphragmatic injury following penetrating trauma

Anthony Shiflett, Joe DuBose, and Demetrios Demetriades

A 40-year-old male sustains a stab wound to the left lower chest. On arrival to the emergency room, he is awake and alert. His airway is patent, his breathing unlabored, and his breath sounds are equal bilaterally. His blood pressure and pulse are normal. On secondary survey, there is a 2-cm stab wound anterior to the anterior axillary line at the level of the 10th intercostal space. He has mild left upper quadrant tenderness focally at the wound site, but no peritonitis. A plain chest radiograph is obtained, which reveals no evidence of pneumo- or hemothorax or free air under the diaphragm. A focused ultrasound (FAST) examination is normal.

The patient is admitted to the trauma observation area for serial exams and a repeat plain radiograph of the chest 6 h after admission. This film is normal, and the patient is scheduled for a diagnostic laparoscopy the following morning for evaluation of his diaphragm. Ten hours after admission, the patient undergoes laparoscopic exploration, which identifies a 2-cm left diaphragmatic laceration. No other injuries are found, and a primary repair of the diaphragm is performed laparoscopically. A 24 French thoracostomy tube is placed. The postoperative course is uneventful, and the chest tube is removed the next day. A final radiograph confirms no residual pneumothorax, and the patient is discharged home on the third hospital day.

Figure 9.1 Omentum protruding through diaphragmatic defect following penetrating injury.

DEMOGRAPHICS AND EPIDEMIOLOGY

Diaphragm injuries are uncommon, but not rare, sequelae of trauma. Among blunt trauma patients undergoing laparotomy or thoracotomy, rates between 0.8% and 9.5% have been reported. (1, 2) The reported incidence of diaphragm injuries following penetrating trauma in the left thoracoabdominal area (the region bounded by the nipples superiorly and costal margin laterally and inferiorly) is particularly high. In a prospective study by Murray et al. (3), diaphragm injury was identified in 42% of patients following penetrating mechanisms (59% of gunshot wounds and 32% of stab wounds). There was no significant difference in this series between anterior, lateral, and posterior thoracoabdominal injury sites (22%, 27%, and 22%, respectively). In another study by Uribe et al. (4), the investigators performed routine laparoscopy in 28 patients with penetrating thoracoabdominal trauma and found diaphragmatic injury in 32%. Other authors have reported an incidence as high as 50% following penetrating mechanisms.(3, 5–7)

CLINICAL PRESENTATION

Isolated injuries to the diaphragm may occur in 25%–33% of patients following penetrating trauma.(3, 6, 8) These patients may be completely asymptomatic or have only minimal abdominal tenderness or a hemothorax. In one series of 41 patients with isolated diaphragmatic injuries, 10 (24%) were completely asymptomatic on admission.(8) Other authors have reported rates of asymptomatic diaphragm injury following blunt mechanisms in up to 20% of patients.(9) A high index of suspicion, therefore, remains the cornerstone of early diagnosis, and all patients with penetrating trauma to the left thoracoabdominal area should be evaluated for diaphragmatic injury.

NATURAL HISTORY OF UNREPAIRED DIAPHRAGM INJURIES

The natural history of unrepaired diaphragmatic injuries is not known. It is possible that some small injuries heal without adverse sequela.(10–13) For right-sided diaphragmatic injuries, particularly those in posterior positions, the liver may confer some protection against the introduction of abdominal contents through the laceration, thereby permitting unimpeded healing. However, many, particularly larger injuries, fail to heal and can result in late diaphragmatic hernias. It has been suggested that the relative thinness of the diaphragm, combined with the constant motion of the muscle, may impede healing. Another possible mechanism is the early herniation of omentum through the diaphragmatic wound, which prevents healing and allows further herniation at a later stage (Figure 9.1)

When they do occur, diaphragmatic hernias may be completely asymptomatic for many years prior to their discovery on a routine chest film (Figure 9.2a–c). In one study by Degiannis et al. 64% of diaphragmatic hernias due to penetrating mechanisms were
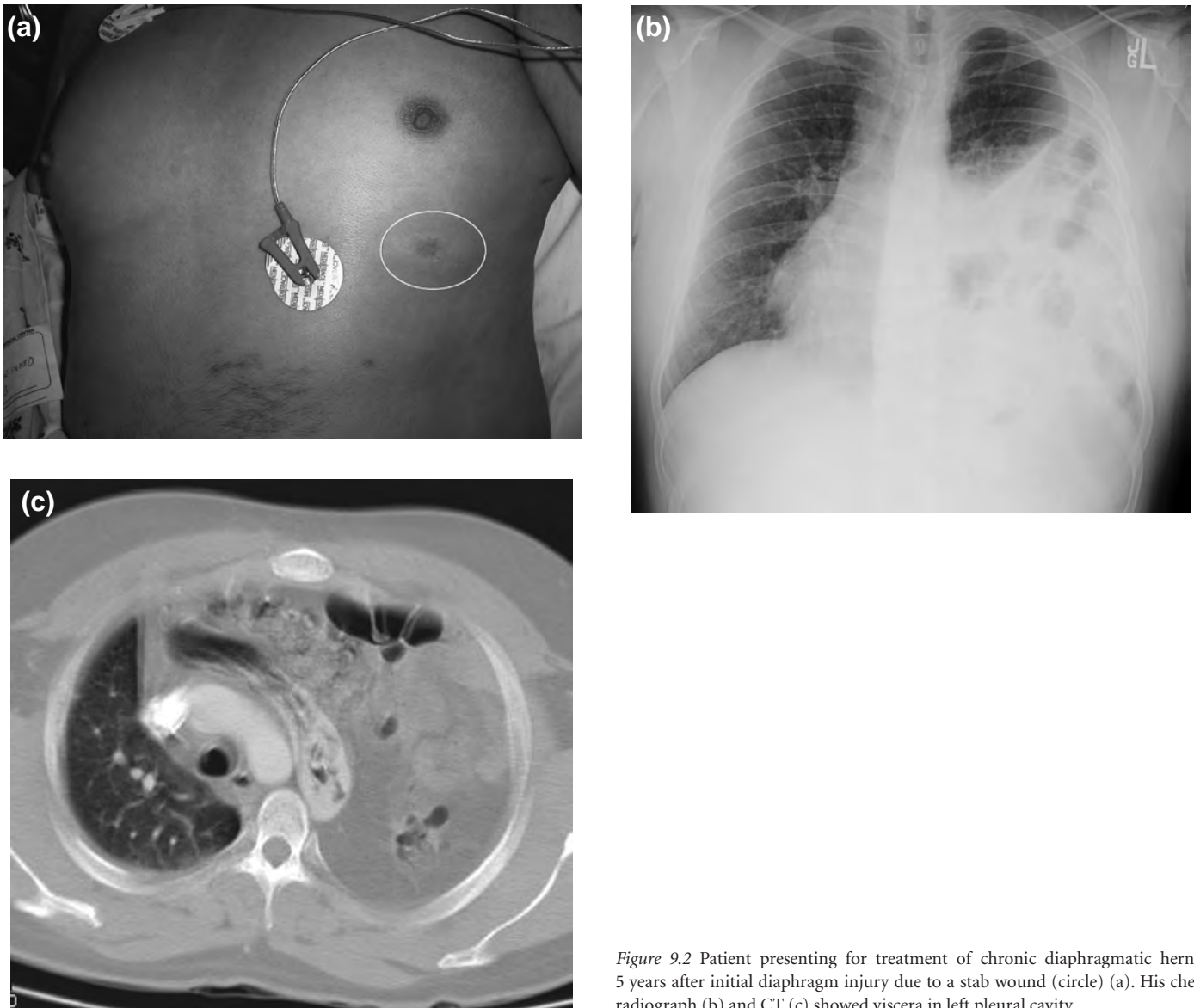
Figure 9.2 Patient presenting for treatment of chronic diaphragmatic hernia 5 years after initial diaphragm injury due to a stab wound (circle) (a). His chest radiograph (b) and CT (c) showed viscera in left pleural cavity.

discovered during the first admission, with the remaining 36% discovered during a later hospitalization.(14) Some patients may present with complaints of nonspecific upper abdominal discomfort, the most common symptom of diaphragmatic hernia. The correct diagnosis may be missed during initial work-up, revealing itself only after more extensive evaluation for peptic ulcer disease, pancreatitis, biliary dysfunction, or pulmonary infections. In complicated cases, these patients may even present with intestinal obstruction or respiratory distress. If neglected hernia contents strangulate, the result may manifest in the form of sepsis and shock.

DIAGNOSIS

A chest X-ray (CXR) is usually the initial investigation utilized in the investigation for diaphragmatic injury. The findings of plain films may range from minimal to dramatic. In a prospective study of 45 diaphragmatic injuries, Murray et al. (3) reported a normal CXR in 40%, nonspecific findings in 49%, and suspected diaphragmatic injury in only 11%. Radiologic signs suspicious for diaphragmatic injury include an elevated diaphragm (Figure 9.3)

or a hemopneumothorax combined with free air under the diaphragm. In the presence of diaphragmatic hernia, the chest film is more commonly abnormal, frequently demonstrating evidence of hollow viscus within the pleural cavity (Figure 9.4). A small omental, gastric, or bowel herniation, however, may be missed on the initial plain radiography. In chronic cases of diaphragmatic hernia, the chest film may be misread as atelectasis, pleural effusion, pneumonia, lung abscess, or encysted pneumothorax (Figure 9.5). Often some of these patients are treated with antibiotics for pulmonary infections before the correct diagnosis is achieved.

Contrast gastrointestinal (GI) studies may be valuable in the diagnosis of traumatic diaphragmatic hernias, but not in uncomplicated diaphragmatic injuries. The utility of these studies is primarily for the investigation of mature hernias (Figure 9.6), and they are much less useful in the acute setting.

Computed tomography (CT) has a definitive role in the evaluation of diaphragmatic injury (Figure 9.7), but it has a limited role in the evaluation of uncomplicated diaphragmatic injury because of its low sensitivity. With the advancing technology of helical CT
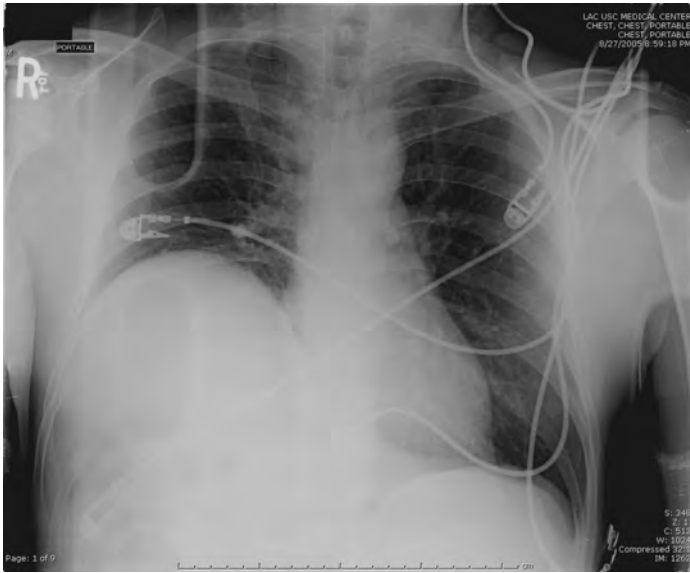
Figure 9.3 Elevated right hemidiaphragm on chest radiograph following diaphragm injury.

Figure 9 5 CT image of encysted pneumothorax mimicking diaphragmatic hernia.
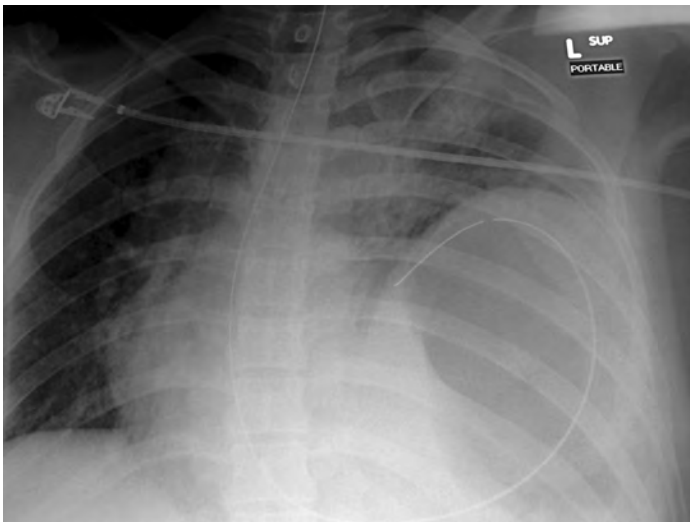

Figure 9.4 Chest radiograph showing an NGT coiled in chest; indicative of gastric migration into the thoracic cavity following diaphragm injury.
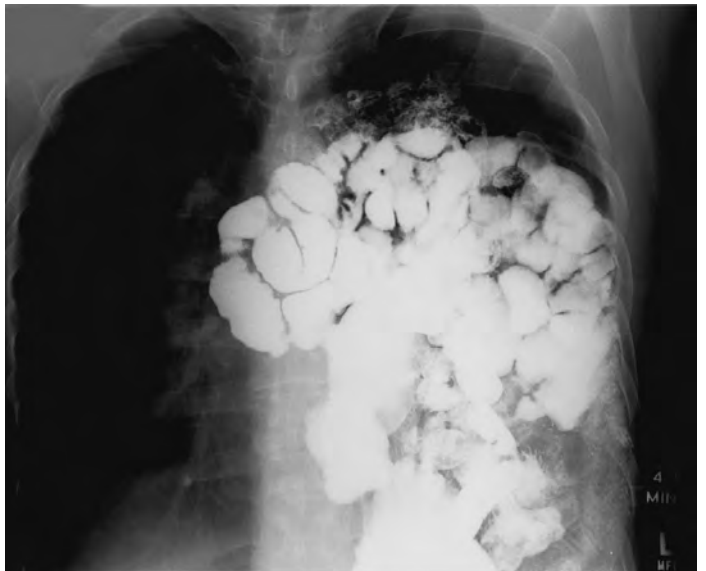

Figure 9.6 Contrast GI study showing visceral contents within left hemithorax in chronic diaphragmatic hernia.

and multislice scanners, however, the role of CT may be redefined. The utility of other noninvasive modalities, including ultrasound and MRI (15, 16), are also of little proven utility at present.

Another investigation that has been used for the diagnosis of occult diaphragmatic injury is diagnostic peritoneal lavage (DPL). Unfortunately, traditional criteria for a "positive" DPL (100,000 RBCs/ml) have been associated with high false-negative rates; efforts to improve the sensitivity of DPL by lowering the diagnostic threshold to 10,000 RBC/ml or even 5,000 RBC/ml (17, 18) have resulted in unacceptably high rates of negative laparotomy. In the presence of diaphragm injury, intra-abdominal blood is preferentially diverted into the chest by the pressure gradient that occurs between the thoracic and abdominal cavities during the mechanics of respiration, decreasing the diagnostic yield of DPL. For these reasons, only a few centers

continue to utilize DPL routinely in the diagnosis of diaphragmatic injury, and this modality has largely been replaced by diagnostic laparoscopy.

Diagnostic laparoscopy is currently the most reliable investigation for the diagnosis of occult diaphragmatic injury and has become the standard practice in many centers, including our own (Figure 9.8). In a prospective study from our institution, Murray et al. (3) performed routine laparoscopy in 57 asymptomatic patients with left thoracoabominal injuries and identified occult diaphragmatic injury in 24%. Growing experience with protocolized approaches that include laparoscopy has established this method as the gold standard in the diagnosis of occult diaphragmatic injuries. Ochsner et al. (19) have also demonstrated that videothoracoscopy can be effectively utilized for a similar purpose, although this technique is not as commonly utilized as laparoscopy. Thoracoscopy

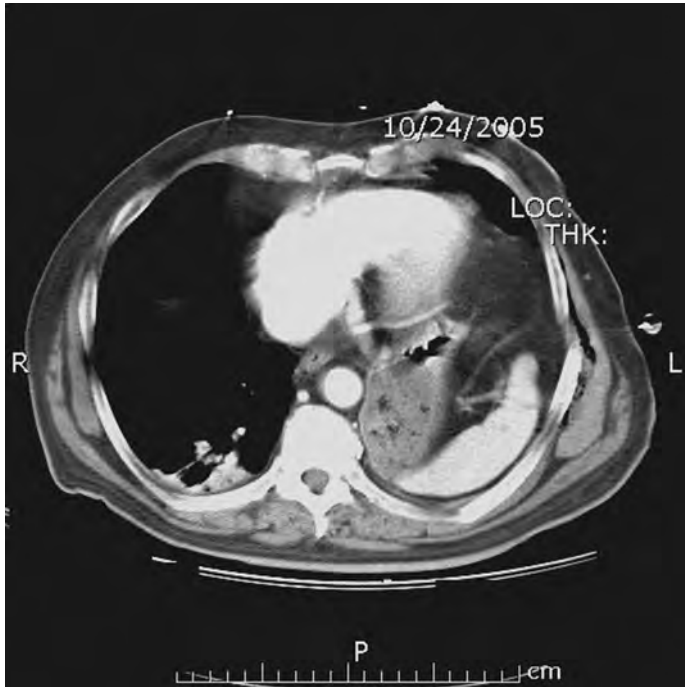*Figure 9.7* Left diaphragm injury with splenic migration into thoracic cavity.

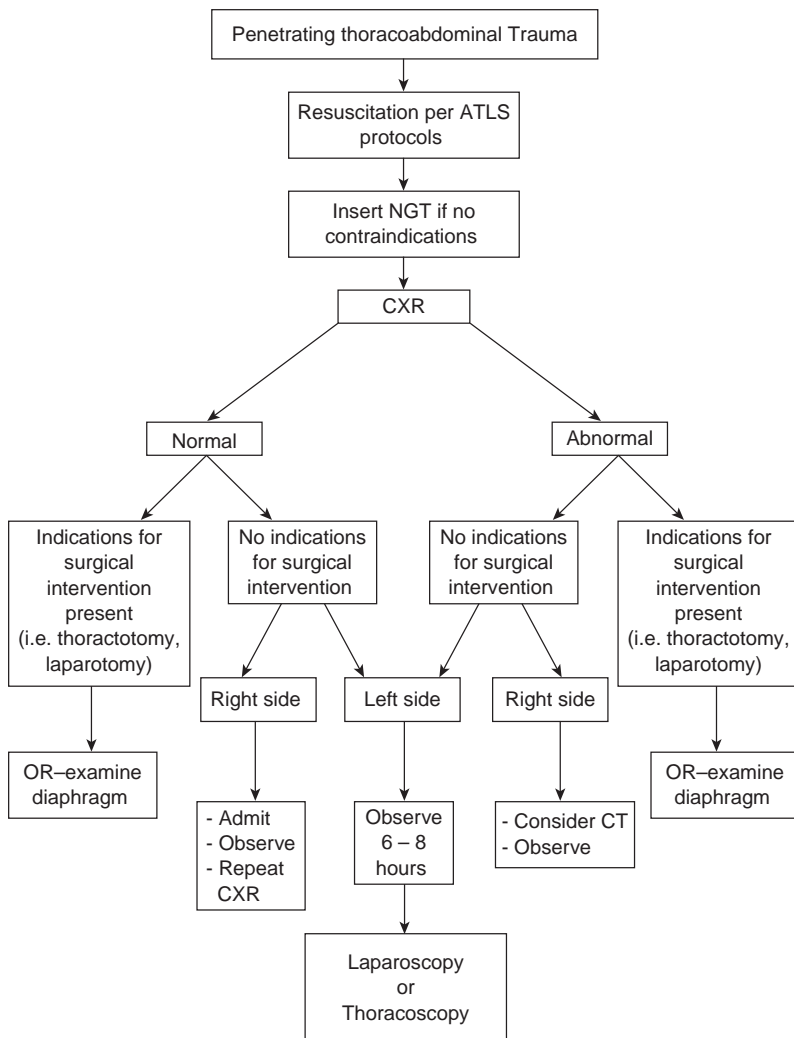*Figure 9.8* Diaphragmatic injury with omental evisceration diagnosed with laparoscopy.

Figure 9.9 LAC/USC algorithm for diagnosis of acute diaphragmatic injury.

might be the preferred approach in cases with residual hemothorax, however, as it permits both treatment of the diaphragmatic injury and facilitates drainage of collected heme in this situation.

As occult diaphragmatic injuries do not commonly represent an urgent threat to life on initial admission, diagnostic laparoscopy can be offered in a semi-elective fashion. The use of delayed laparoscopy for asymptomatic patients, hours after admission, facilitates the reliable exclusion of hollow viscus injury through a period of serial exams and monitoring. It is our practice (Figure 9.9) to offer this procedure only after appropriate evaluation and observation over a 6–8-h period for the development of peritoneal signs. Any diaphragmatic injuries can then be repaired laparoscopically without the concern of missed hollow viscus injuries.

It is important to note that when diaphragmatic hernias are suspected, tube thoracostomy placement should be avoided, if possible, until CT evaluation has been completed. In certain instances, however, a thoracostomy tube will be deemed necessary due to respiratory distress. In these situations, the thoracostomy tube should be placed above the level of the nipple by an experienced provider, and only after careful digital exploration of the chest cavity under sterile technique. Trocar techniques of thoracostomy insertion should be universally avoided.

OPERATIVE MANAGEMENT

Laparoscopy

Diagnostic laparoscopy is performed under general anesthesia with appropriate intraoperative monitoring. Initial port placement should be supra-umbilical, and an angled scope can be utilized to facilitate better visualization. Subsequent second and third 5 mm port sites may afterward be developed under direct visualization if laparoscopic repair of the diaphragm is to be attempted. During insufflation of the abdomen in the presence of diaphragmatic perforation, there is the risk of tension pneumothorax if the patient does not have a thoracostomy tube in place. It is essential that the patient be monitored closely, and any evidence of tachycardia, hypotension, or low oxygen saturation be rapidly communicated so that the abdomen may be deflated and a thoracostomy tube placed. Laparoscopic repair is most commonly performed with "figure of eight," interrupted, size 0 monofilament nonabsorbable suture material (polypropylene). When suturing, the use of adequate traction of the diaphragm is advisable, as this maneuver will prevent inadvertent injury to the heart or lung within the thoracic cavity. Stapled repairs may also be utilized to effect adequate repair. As Murray et al. (20) have previously demonstrated in an animal model of diaphragmatic injury, properly performed sutured and stapled repairs are equivalent in both healing outcomes and tensile strength.

Thoracoscopy

Thoracoscopic techniques are another viable alternative for repair of acute diaphragmatic injuries due to both blunt and penetrating mechanisms.(4, 21, 22) The advantages of thoracoscopic techniques include the ability to adequately evacuate associated hemothorax and better visualization of posterior diaphragmatic injuries. The disadvantages of the technique include the need for placement of a double-lumen endotracheal tube and the need for collapse of the ipsilateral lung to facilitate exposure.

To conduct thoracoscopy, the patient is placed in lateral decubitus position with flexion of the operating table just inferior to the level of the nipples, to open up the intercostal spaces for thorascope insertion and instrumentation. Under general anesthesia with a double-lumen endotracheal tube, selective one-lung ventilation should be confirmed with the anesthesiologist prior to port incision. The initial, thoracoscopic port, is placed at the 7th or 8th intercostal space along the mid-axillary line. Two further instrument ports can then be placed under direct thoracoscopic vision, one in front of the tip of the scapula along the posterior axillary line, and another at the anterior axillary line in the 5th or 6th intercostal space.

Open Repair

Some patients will require more urgent surgical intervention because of hemodynamic instability or peritonitis, in which case there should be no delay in transport to the operative theater. Laparotomy should begin with thorough exploration of the abdominal cavity. Bleeding should then be controlled and bowel injuries addressed before attention is directed toward repair of the injured diaphragm. The entire surface of the diaphragm should be inspected. In the event of herniation of abdominal viscera, a careful reduction and return to anatomical position within the abdomen should be performed. In cases with posterior diaphragmatic injury, the identification of the injury and repair can be greatly facilitated by applying tissue forceps and anterior retraction of the diaphragm. The suction catheter tip should be carefully inserted into the pleural cavity through the diaphragmatic defect and any blood or gastrointestinal contents adequately evacuated. In cases with concomitant hollow viscus injury and gross spillage of enteric contents, diligent washout of the thoracic cavity must be undertaken to prevent later empyema. The diaphragmatic laceration is repaired with "figure of eight," interrupted size 0 monofilament nonabsorbable suture material (polypropylene). A chest tube should always be inserted following repair.

MANAGEMENT OF CHRONIC DIAPHRAGMATIC HERNIAS

Acute injuries of the diaphragm should always be approached through the abdominal cavity, by either laparoscopic or open techniques. The optimal approach to chronic diaphragmatic hernias, however, remains more controversial. Over time, chronic sequestration of abdominal contents within the thoracic cavity may promote the formation of significant adhesions. Liberating the incarcerated viscera from these adhesions using an abdominal approach may prove challenging and

Table 9.1 Diaphragm Injuries:Outcome.

	No.	Mortality (%)	Morbidity (%)	Mean Hospital Stay (days)
No hernia	139	2.9	12.60	6.0
Early diaphragmatic hernia	14	7.1	35.70	11.6
Late diaphragmatic hernia	10	30.0	60.00	20.0

Source: Demetriades D.(8)

place the patient at risk of inadvertent enterotomy or other injury during adhesiolysis. For this reason, some surgeons, especially those with thoracic training, prefer the use of thoracotomy for the treatment of chronic hernias. The routine use of this approach, however, confers significant risk of pulmonary sequela and limits the evaluation of the abdominal contents once they have been returned to the abdominal cavity. In our experience, a trans-abdominal approach is preferred, for both its ease of execution and safety. The trans-abdominal approach should always be utilized in the setting of suspected strangulation and possible gangrenous hollow viscus. Even in the setting of a chronic diaphragmatic hernia, we have demonstrated that an abdominal approach to repair can be safely performed with outcomes similar to those of thoracic techniques and a low need for an additional incision to grant access to the thoracic cavity.(23) Given the important concerns with both modalities, however, the optimal intervention must be individualized to both patient presentation and surgeon experience with each approach.

In most instances, primary repair of the diaphragmatic defect is possible even in the setting of chronic diaphragmatic hernia. In select cases, however, the defect may prove too large or the peripheral edges chronically attenuated to facilitate adequate re-approximation. In these cases, mesh interposition techniques may be effectively employed.

MORBIDITY AND MORTALITY
Mortality following uncomplicated diaphragmatic injury is almost universally due to associated injuries. The most common complications in this setting are atelectasis, pleural effusion, and empyema. Patients are at particular risk for the latter if they have suffered a hollow-viscus injury in association with their diaphragmatic laceration.

Complicated diaphragm injury, involving symptomatic herniation of visceral contents into the thoracic cavity, has a much higher risk of complications (Table 9.1). Strangulation of the colon is associated with a much higher mortality than gastric or small bowel, due to the comparatively more tenuous blood supply and higher bacterial load of its contents. The bacterial load released from such colonic perforations is much higher than encountered, following small bowel or gastric counterparts, further contributing to adverse sequela. Particularly if the diagnosis is delayed, these injuries may result in incarcerated or even strangulated visceral contents within the chest, representing significant risk for patient morbidity and mortality.

CONCLUSION
Unfortunately, there are no studies which provide class I evidence to guide the diagnosis and management of diaphragmatic injuries. Based on available data, however, there appears to be a high incidence of occult diaphragmatic injury following penetrating trauma. Several class II, prospective studies (3, 24, 25) have demonstrated that diagnostic laparoscopy represents the present standard for the evaluation of such patients. In our opinion, diagnostic laparoscopy should therefore be offered after 6–8 h of observation to all patients with left thoracoabdominal injuries, who do not have other indications for emergent surgery. Failure to diagnose diaphragmatic injury may result in serious complications or death for the patient, and confers significant medicolegal risk upon the treating surgeon.

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10 Blunt liver injury

Leslie Kobayashi, Donald Green, and Peter Rhee

A 35-year-old woman was a restrained passenger when her car was hit by another car on her side. She arrived at the emergency room 25 minutes after collision. She appeared confused, her systolic blood pressure was 78 mmHg and her heart rate was 130 bpm. On secondary survey, there was slight abdominal distension and tenderness to her right side. Her upper arm and thigh were deformed. She had tenderness to her hip.

GENERAL OVERVIEW

Liver trauma can be defined as any parenchymal damage to the liver secondary to trauma, including hematoma, laceration or avulsion, as well as damage to vascular or biliary structures.

The American Association for the Surgery of Trauma (AAST) created a grading system for liver injury in 1989 and revised it in 1994 (Table 10.1). The categories are divided based on both computerized tomography (CT) scan and intraoperative findings, and incorporate segmental anatomy in the grading of injuries.(1, 2) It is quick and accurate and can be used to guide treatment.

Liver injury is a common occurrence in blunt trauma, with an incidence of 5–6%. The liver is the most commonly injured solid organ in both blunt and penetrating trauma.(1) Most liver injuries are due to blunt trauma, with motor vehicle accidents accounting for the vast majority (72–82%) of injuries in most studies.(3–5)

Most liver injuries are of minor to moderate in severity (Grade I–III). A multicenter study revealed 86% to be Grade I–III, 10% Grade IV, and even fewer than 4% Grade V.(5) The injury pattern generally occurs along anatomic segments and tends to involve primarily venous structures. The low-pressure system in the hepatic and portal veins along with the anatomic limitations such as the triangular, coronary, and falciform ligaments allows for tamponade of most injuries.(4) In fact, the vast majority of injuries stop bleeding without intervention and most studies show that 60–80% of liver injuries had stopped bleeding by the time of laparotomy.(4) However, when severely injured, the liver is a "formidable and treacherous enemy".(6)

DIAGNOSTIC TESTS

Focused Assessment with Sonography for Trauma and Diagnostic Peritoneal Lavage

In the hypotensive blunt trauma patient, determining the source of hemorrhage is the first priority. In patients who are moving their extremities (thus excluding neurogenic shock) and are not bleeding externally, finding the internal source of hemorrhage is the key. The focused assessment with sonography for trauma (FAST) can be extremely helpful in these situations. A positive study, i.e., the presence of blood in the peritoneal cavity, is highly reliable and suggests that the abdomen is the source of bleeding. In contrast, a negative FAST does not exclude intraperitoneal hemorrhage or organ injury. It should be noted that the FAST

Table 10.1 Liver injury scale (1994 revision).

Grade*	Type of Injury	Description of injury	ICD-9	AIS-90
I	Hematoma	Subcapsular, <10% surface area	864.01 864.11	2
	Laceration	Capsular tear, <1 cm parenchymal depth	864.02 854.12	2
II	Hematoma	Subcapsular, 10% to 50% surface area: intraparenchymal <10 cm in diameter	864.01 864.11	2
	Laceration	Capsular tear 1–3 parenchymal depth, <10 cm in length	864.03 864.13	2
III	Hematoma	Subcapsular, >50%, surface area of ruptured subcapsular or parenchymal hematoma; interparenchyma hematoma >10cm or expanding		3
	Laceration	>3cm parenchymal depth	864.04 864.14	3
IV	Laceration	Parenchymal disruption involving 25% and 75% hepatic lobe or 1-3 Couinaud's segments	864.04 864.14	4
V	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud's segments within a single lobe		5
	Vascular	Juxtahepatic venous injuries; i.e., retrohepatic venacava/central major hepatic veins		5
VI	Vascular	Hepatic avulsion		6

*Advance one grade for multiple injuries up to grade III.
From Moore et al. [4]; with permission.

exam aims to identify the presence of free fluid in the peritoneal cavity and not to diagnose specific organ injuries. It is also important to remember that at least 200–300 ml of blood is required in the peritoneal cavity before it can be seen on FAST.(1)

A positive FAST in the hypotensive blunt trauma patient that does not respond to resuscitation warrants exploratory laparotomy. On the other hand, if the FAST is negative or indeterminate in this setting, diagnostic peritoneal lavage (DPL) can be of use. Many surgeons perform diagnostic peritoneal aspiration only in hypotensive patients as lavage can be confusing. The rationale is that if a patient has bled sufficiently into the peritoneal cavity to be hypotensive, then the aspirate should be grossly positive. Lavage on the other hand only requires 28cc of blood to mix with the one liter infusion in order for the lavage to be positive by cell count (greater than 100,000 red cells)

TRAUMA, CRITICAL CARE AND SURGICAL EMERGENCIES

and this cell count positive lavage can look very bloody. This often fools the surgeon into thinking that the blood loss that caused hypotension is from the abdomen when it is not.

Computerized Tomography Scanning

For stable patients, CT is the standard method to identify or exclude intra-abdominal injuries and hemorrhage. Both oral and intravenous contrast agents can be used, but some have questioned the value of oral contrast. Once CT has characterized the liver injury, the question is whether therapy is needed. While it is generally true that lower grade of injuries (Grade I–III) can be managed without intervention, many severe injuries (Grade IV–V) do not always require surgical therapy and are not a contraindication to nonoperative management although they are more prone to failure (21–38% success rate compared to > 95% for minor injuries, (5)). Mortality and morbidity also increase with grading.(5, 7)

There are several CT findings that can predict nonoperative failure. For example, left lobe injuries seem to be more prone to bleeding than right posterior lobe or split liver injuries, even if the latter are larger. Some believe that this is because the ligamentous attachments of the right lobe are more likely to tamponade an injury.(8) Extension of injury into the hepatic veins is also a predictor of nonoperative failure (88–91%).(9) Furthermore, the absence of extravasation and hepatic vein involvement on CT scan is 100% predictive of a negative angiogram, and no patient who lacks both findings requires either embolization or surgery. Other predictors of nonoperative failure include hemoperitoneum ≥ 6 compartments (bilateral subphrenic areas, Morrison pouch, bilateral paracolic areas, Douglas pouch, and inter-loop space), laceration > 6 cm, and porta-hepatis involvement. The presence of a "blush" on CT scan suggests ongoing arterial bleeding or arterio-venous malformation (AVM).(10–13) These conditions must be addressed either surgically in the unstable patient or by angio-embolization in the stable patient. High success rates for arterial embolization were reported also in patients with blush from Grades IV and V liver injuries.(5) This suggests that all stable patients with a "blush" should be treated with this method regardless of their degree of liver injury. The class of evidence for CT and management of liver injuries are shown in Table 10.2.

> The trauma room chest and pelvis radiographs show broken ribs with small hemothorax and left iliac wing fracture. Abdominal CT scan demonstrates a hematoma encompassing approximately 30% of the right lobe of the liver, with rupture into the peritoneal cavity resulting in hemoperitoneum; the hematoma includes several areas of "contrast blush." These findings are consistent with a Grade IV liver injury.

MANAGEMENT

Several decades ago most liver injuries were diagnosed intraoperatively and carried high mortality. For example, during World War I mortality for liver injury was ~66%. The application of rapid surgical treatment and open drainage techniques reduced mortality from liver injuries to 29% in World War II.(14) More recently, the introduction of advanced imaging techniques such as abdominal ultrasound and CT scanners

Table10.2 Evidence Based Recommendations for Treatment of Blunt Liver Injury.

Treatment	Recommendation	Class
CT scan grading	Useful reliable tool for grading severity of injury and can be used to help predict both need for operative intervention and intraoperative findings	1B
Nonoperative management Grade I–III	Most desirable strategy for *any* hemodynamically stable patient provided no evidence of other intra-abdominal injury requiring laparotomy (e.g., hollow viscous injury)	1B
Grade IV–V	Can be used for hemodynamically stable patients regardless of other injuries	2A
Angiography	Should be performed for any hemodynamically stable patient with evidence of active extravasation or AVM	1B
Observation period	Should last 24–48 h in closely monitored setting	1B
Factor VII	Cannot be recommended due to paucity of data in trauma population	NA
Operative	Type of repair highly dependent on type of injury and experience of surgeon, and capabilities of each hospital/OR. No specific strategy can be recommended	
Time to pack removal	Packs should be removed between 24 and 48 h	1B
Repeat CT scan	Should be performed after some nonoperatively managed patients with high-grade injury (IV–V), or post-operatively for surgically managed patients	2B
Minimally invasive treatment of complications	ERCP and percutaneous drainage are equally if not more effective at treating complications of biloma, biliary leak, abscess. Angiography and embolization are effective at treating complication of arterio-bilious fistula	1B

as well as minimally invasive methodologies including angiography, endoscopic retrograde cholangiopancreatography (ERCP), percutaneous drainage, and laparoscopy, have dramatically changed the management of liver injury and reduced mortality to 7–15%.(4, 5, 7, 15, 16) In fact, studies specifically investigating liver-related mortality show that only 0.4–4% of deaths are directly related to liver injuries.(4, 5) Patients with liver injuries are now diagnosed and classified shortly after admission and quickly triaged to nonoperative or operative treatment.

Nonoperative

The trend toward nonoperative management started in the 1980s and early 1990s by pediatric surgeons, who successfully managed liver injuries without surgical intervention. The lessons learned from these pediatric surgeons eventually gained popularity in adult trauma. Additional influences included the drift away from the use of DPL to CT scanning for abdominal evaluation. DPL is often positive with clinically insignificant amount of blood, which prompts many unnecessary operations for insignificant liver injuries.

Figure 10.1 Grade V liver injury with free intraperitoneal blood around spleen and liver.

Most early experience with nonoperative management was gained in patients with minor or moderate injuries (Grades I–III). However, more recent experience at Level I trauma centers have shown success also in stable patients with Grades IV and V injuries. The decision whether a patient is appropriate for nonoperative management could be trivial or complex. For example, asymptomatic stable patients who require minimal fluid resuscitation should be assigned to nonoperative management. Similarly, patients with diffuse peritonitis should be taken emergently to the operating room. In contrast, patients with signs of ongoing bleeding requiring continuous resuscitation may present a challenge to the trauma surgeon, as the optimal therapeutic approach to bleeding control has not yet been determined.

Initially, criteria for expectant management included intact mental status, absence of severe traumatic intracranial bleeding, age < 65 years, reliable abdominal exam, and transfusion of < 2 units of packed red blood cells. Inclusion radiological criteria were Grade I–III injury or hemoperitoneum < 500 ml on CT scan. Success rates for nonoperative management using these criteria were 80–95%, and 65–85% of patients with liver injury met these criteria.(4, 5, 7, 15) However, current data from several studies indicate that even Grade IV and V injuries, age > 65 years, or comatose states are not contraindications to nonoperative management. For example, success rate of up to 40% were reported in stable patients with Grade IV and V injuries (5) (Figure 10.1). Furthermore, no statistically significant differences could be identified among failure and infection rates in patients with a GCS of 15 (5.9%), 8–14 (6.2%), and 3–7 (9%).

For many years, elderly patients were not considered optimal candidates for nonoperative management. Decrease physiological reserve and a thinner liver capsule were commonly cited to justify this policy. To resolve this issue, a study was specifically conducted in liver injury patients older than 55 years (mean 69 years). In this study, nonoperative management was pursued in 61% of patients and was successful in 97%. The overall 24-h mortality was 13%. All deaths in the nonoperative group were unrelated to the liver injury.(17)

Overall, 65–88% of all patients with blunt liver injury can be managed initially nonoperatively with a success rate of 85–95%. (4, 5, 7, 18–20) A review of all solid organ injuries registered in the National Trauma Database from 1994 to 2003 revealed 35,510 liver injuries. Seventy-eight percent of those were due to blunt trauma and 83% were managed nonoperatively with a 95% success rate. The study noted that the percentage of patients managed nonoperatively increased during that time period from 75 to 87% while mortality remained steady at 13–15%.(3)

> The patient was intubated and after fluid bolus her blood pressure normalized. Her fractures were reduced and immobilized by the orthopedic surgeon and a pelvic binder was placed for her pelvic fracture. Throughout these procedures, the patient's blood pressure remained normal. The admitting surgeon decided with the multiple other injuries to admit the patient to the intensive care unit and proceed with nonoperative management of her liver injury.

Angio-embolization
Stable patients with any injury grade and evidence of intraparenchymal extravasation of contrast material (blush) are candidates for angiography and possible embolization. Angio-embolization can be used before, immediately after, or instead of surgery. It also has a significant role in managing late complications such as AVMs. It is required in 5–6% of patients with liver injury and has a success rate of 80–100%.(18, 21, 22) Some patients fail embolization, mostly when the source of bleeding is venous. (23) It should also be kept in mind that the majority of blood flow to the liver is not arterial.

CT scan findings are the main indicator of angiographic intervention and are good predictors of arterial injury amenable to angio-embolization. CT scan has a sensitivity approaching 100%, a specificity of 76%, and a positive predictive value for extravasation on angiography of 89%.(23) However, with an 11–36% false-positive rate, many patients undergo angiography with no significant benefit although the morbidity associated with diagnostic angiography alone is minimal.(9, 24) In contrast, there are significant morbidities when embolization is performed. A 2003 study of 26 patients who underwent angio-embolization for liver injury revealed mortality and morbidity of 27% and 58%, respectively. Complications included hepatic necrosis, abscess, and bile leak.(24, 25) In this study, the timing of angiography appeared to affect morbidity and mortality; better outcomes were observed in patients undergoing early compared with late angiography.

A rare complication associated with angio-embolization, particularly of the right hepatic artery and its branches, is gallbladder necrosis. Cholecystectomy was required in the few case reports that described this complication.

The patient was admitted to the surgical intensive care unit (SICU) from the emergency department. She was left on full venilatory support during the observation period and was started on maintenance fluids. The trauma surgery team on call ordered pain medication for her multiple injuries and light sedation, as well as blood counts, coagulation panels and blood gases every 4 h. At the time of her admission to the SICU, her hemoglobin was 11, and she had a small metabolic acidosis. The trauma team gave her a small fluid bolus to improve her perfusion. She responded with adequate urine output and normalization of her acid base status. She did not have any episodes of hypotension since admission, and her heart rate improved after the addition of pain medication; however, it remained mildly elevated in the low 100s. Eight hours after admission, the ICU nurse called the team to inform them that the patient's hemoglobin, which had been stable at 11 up to that point, had dropped to 8. After evaluation, the trauma team determined that the patient remained hemodynamically stable and that there was no peritonitis on examination of her abdomen. Because of the drop in hemoglobin and concern for ongoing bleeding, the admitting surgeon sent the patient to angiography for possible embolization. Angiography revealed a small pseudoaneurysm in the damaged right lobe parenchyma which was coiled; it also revealed a small area of active extravasation from the edge of the ruptured hematoma which was embolized with gelfoam, with good occlusion of extravasation. Pelvic angiography performed at the same time revealed no evidence of active extravasation. The patient was taken back to the surgical ICU for further observation.

For How Long Should Patients Be Observed?

Most studies of nonoperative management identified failure as significant anemia or onset of hemodynamic instability requiring surgery within the first 12–24 h. Such failures occur mainly in the first 12–24 h and rarely after 48 h.(3, 4, 18, 26, 27) For example, one prospective trial demonstrated that 75% of failures occurred within the first 18 h.(18) Another study of 905 failures found that 50% occurred in the first 24 h while additional 40% occurred 24–48 h after admission.(4)

When to Operate?

Given the high success rate of nonoperative management and to minimize blood transfusion, it is important to point out how to promptly identify failures. Although all agree that failure of nonoperative care occurs in the presence of ongoing, clinically significant bleeding, the time and quantitative definitions of failure are still obscure. Nevertheless, most studies consider failure when transfusion requirements exceed 3–4 units, when there is a continuous drop in hemoglobin concentration, and/or in the presence of hemodynamic instability or peritonitis.(4, 5, 7, 28, 29, 30) When such patients are taken to the operating room, bleeding is found in 67% of them.

Clinical predictors of failure were described. These include low admission systolic blood pressure, elevated Injury Severity Score

(ISS) or base deficit, non-liver solid organ injury, positive FAST, and the need for any blood transfusion.(4, 5, 28) CT scan predictors of failure were discussed above. Overall, there is no definite contra-indication to nonoperative management except for hemodynamic instability unresponsive to fluid and blood resuscitation. Patients with the previously mentioned clinical and CT scan findings would benefit from ICU monitoring and low threshold for operative control of bleeding.

Overnight the patient's blood pressure and hemoglobin measurements remained stable. On hospital day 2, the patient's sedation was lightened and she began to follow commands. However, when evaluated on morning rounds by the admitting trauma team, the patient was found to have peritoneal signs and was taken emergently to the operating room for exploration.

Operative Approach

Satisfactory operative repair of significant liver injuries continues to be a challenge even for the experienced trauma surgeons. Major liver injuries are difficult to approach and control surgically. In addition, since major injuries are rare, many surgeons do not have significant experience in the operative management of liver trauma.

Because many operations for liver injury follow failed nonoperative management, the exact location of injury is frequently known to the surgeon preoperatively. In this case, some measures must be taken while getting the patient ready for surgery. First, a cell saver should be set up urgently, as hollow viscous contamination is rare in blunt trauma. Second, the blood bank should be notified of a possible activation of the massive transfusion protocols. Third, a rapid transfusion system as well as an argon beam should often be made available.

The liver has a dual blood supply consisting of the portal vein and hepatic artery, both of which course through the porta hepatis. The drainage of the liver is via the hepatic veins, which empty directly into the inferior vena cava (IVC). The vast majority of patients has a right left, and middle hepatic vein, which usually merge in the extraparenchymal soft tissue before emptying into the IVC. There is also a variable number of posterior short hepatic veins, which drain directly from the caudate lobe into the retro hepatic IVC, and which can also be a source of major hemorrhage if disrupted. Because the right sided hepatic vascular structures are located more centrally and deeply within the liver parenchyma, and with more direct venous connection to the IVC, right hepatic vascular injuries are often more difficult to isolate and control. Furthermore, they are associated with higher morbidity and mortality than left hepatic vascular injuries, and more often they require total vascular isolation or shunting of the liver for repair.(31)

Packing for Hemorrhage from Severe Liver Injuries

Empiric "four-quadrant packing" is the first step in the management of massive hemoperitoneum in blunt trauma patients when the source of bleeding is unknown. This facilitates the quick removal of blood, to find the source of hemorrhage. However,

it should not be thought of as a way to stop bleeding as it does not provide enough pressure to stop arterial bleeding or massive venous bleeding. Packing and letting anesthesia "catch up" can be useful at times, but often the patient will have increased bleeding due to continued uncontrolled bleeding under the packing, and the increased fluids infused can worsen the situation. Some now avoid the four-quadrant packing initially as in relatively stable patients, the cell saver is used.

Once the liver has been identified as the source of bleeding, liver packing should be optimized. This involves tight compression of the injured lobe in a sandwich of laparotomy sponges placed above and below the injured area. Liver packing, which is required in 5–36% of moderate to severe liver injuries (32), is quick, easy to perform, and associated with 86% survival. In damage control scenarios, temporary packing allows for quick return to the ICU for rapid resuscitation, re-warming, and reversal of acidosis and coagulopathy. Temporary liver packing results in hemorrhage control in up to 80% of patients.(32)

The use of appropriate packing technique is crucial for establishing adequate tamponade effect. Typically, packing starts with complete mobilization of the liver by dividing the falciform, triangular and coronary ligaments. Next, the injured lobe is sandwiched tightly by placing the packs anteriorly and posteriorly between the liver and the chest wall and back. Between 11 and 13 pads are usually required to appropriately tamponade the liver in this fashion.(1)

While tight liver packing temporarily controls bleeding, it may also have untoward hemodynamic and respiratory effects. For example, the packed sponges may compress the IVC and lead to decreased venous return and hypotension. In addition, the packs may apply pressure on the diaphragm, which could lead to increased peak airway pressures and difficulty in ventilation. Thus, good communication between the surgeon and the anesthesiologists is critical to effective packing devoid of major physiologic derangements.

Liver mobilization should be avoided in the presence of a hematoma in the ligaments or tissues around the hepatic veins, as severing these structures may compromise the tamponade effect. In this case, pads can be placed anteriorly to compress the liver, IVC, and hepatic veins posteriorly against the spine and back.

Abdominal wall closure after packing is controversial as it may put the patient at higher risk for developing abdominal compartment syndrome. Others feel that it is a requirement for creating the pressure necessary to stop the bleeding. If the abdomen is closed after packing, the fascia is often preserved for the definitive closure, and skin closure is used to provide some tamponade and keep the fascia in proximity of the midline. Otherwise, the patient will not be able to get the fascia closed at later stages. The abdomen being left open is also thought to increase the fluid requirements as inflammation is increased; the temperature of the bowel is lower and fluids are lost through the edges. This will contribute to the inability to ultimately close the abdomen. Some feel that the placement of the vacuum-assisted closure device (VAC) is convenient and causes increased intra-abdominal compartment pressure around the liver, even though it causes an overall negative pressure. Leaving the abdomen open was popular, but most surgeons are finding it unnecessary, and the multitudes of complications from an open abdomen are teaching us that this is not wise.

Another technical challenge is when and how should the packs be removed? When removing the packs at the second surgery, bleeding from the raw surface is frequent as the packs are removed. To prevent this, the packs can be moistened prior to removal to decrease trauma to the raw surface, and others advocate placing plastic drapes or absorbable hemostatic agents such as gelfoam or vicryl mesh between the packs and the liver surface at the time of initial packing.(1) As mentioned above, absorbable mesh netting can also be placed either directly over the injured parenchyma and sutured into place prior to the placement of packs or wrapped around the liver and tied beneath the packs. Advocates recommend the mesh as it can also act to tamponade bleeding and holds the injured parenchyma together. However placement of the mesh can sometimes be technically challenging and it is not always available in every trauma situation. Absorbable meshes in a bag type format are now available that allow the liver to be slipped into the bag and an adjustable drawstring can be tightened to quickly and easily tamponade the injured liver. Plastic nonadherent balloon type devices that can be wrapped around the liver are being developed.

The optimal time for pack removal is still debated. On one hand, it is important to leave the packs long enough to allow full resuscitation of the patient and prevent re-bleeding. On the other hand, prolonged packing could increase the risk for abdominal infection and organ injury. Studies examining the timing of pack removal demonstrated increased incidence of sepsis (27–87%) when packs are removed later than 72 h.(1) Furthermore, these studies suggest that the ideal time for pack removal is 24–48 h after the initial surgery.(1, 32) Taking the patient as soon as the patient is ready will ensure that the inflammatory phase is minimized and the chances of closing the abdomen is higher.

Repair

Simple lacerations can often be controlled with the application of large, blunt sutures in a simple, locking, or mattress configuration, which bring together intact liver parenchyma over the defect to allow for tamponade of venous bleeding. (1, 15) This technique can be augmented with placement of topical hemostatic agents, argon coagulation, or electrocautery. Larger defects can be filled with viable omentum secured with several liver sutures. The filling of the wound cavity with living tissue, which provides macrophages and other mediators that promote healing, was reported to decrease the risk of liver abscesses. This technique was first described in 1980.(33) In this initial report, hemorrhage was controlled in 95% of 104 patients with liver injury, and mortality has been 8% only. A follow-up study in 1991 suggested that viable omental packing can be successfully applied to juxtahepatic venous injuries with the lowest reported mortality for these injuries in the literature of 20.5%.(33) Others found that this technique is only applicable to major venous injuries that have decompressed through a parenchymal injury.(33)

Topical Hemostatic Agents, Argon Beam, Cavitron Ultrasonic Surgical Aspirator, Intra-op Ultrasound

Several types of topical hemostatic agents are currently available; most contain thrombin or fibrin or a combination of the two with

calcium and act to promote coagulation. They may have limited application in the acute trauma situation because they have varying preparation times and occasionally require special equipment for mixing, thawing, and application. They are also less effective in a wet environment.

Argon beam coagulation clears liver tissue of blood via transmission of ionizing energy; it has a broad area of application with minimal depth of penetration. The maximum temperature reached by the beam application is 110°F, which helps lessen tissue necrosis.(34)

Fluid-enhanced radio frequency ablation (RFA) can also be applied. In this technique, fluid enhances transmission of radio frequency energy to tissues, causing collagen contraction and hence vessel contraction, promoting coagulation and decreasing bleeding. The maximal temperature reached is 100°, again minimizing tissue necrosis.(34) Both RFA and argon beam are useful adjuncts in the operating room and can be used alone or in combination with suture ligation, finger fracture techniques, and other methods of hemostasis. However, both require special equipment, which may not be available at every institution at all hours.

The CUSA or Cavitron Ultrasonic Surgical Aspirator is a device which uses piezoelectric energy converted in the handheld tip to rapid frequency vibrations; the mechanical force is then transferred to tissues through a liquid to create cavitations. This cavitation action liquefies fibrous or fluid filled tissues like, brain, scar and liver while preserving elastic or collagen-rich structures, like blood vessels and nerves. The CUSA has been used in elective liver resections with some series showing significant decrease in blood loss. However, the only randomized controlled trial in elective liver resections, comparing traditional clamp and crush technique with inflow occlusion to other modern devices, showed no advantage to use of the CUSA on intraoperative blood loss, or speed of transaction.(35) No studies have been performed on trauma patients, although a 10 year retrospective from France does mention successful use of CUSA for necrosectomy or segmentectomy on patients with liver trauma.(36) However, these patients were all treated semi-electively after stabilization at other centers with packing or embolization.

Again, CUSA requires specialized equipment, both a sterilized handpiece and the ultrasonic generating device, which may not be available in all hospitals, and certainly not in all operating rooms.

Intraoperative ultrasound may be helpful in localizing injured vessels, so that finger fracture technique can be guided. Again, equipment may not be immediately available in all operating rooms.

Non-anatomical and Anatomical Resection

Non-anatomical liver resection may be required in the presence of a destructive injury, which bleeds profusely and which occupies part of the hepatic lobe. In this case resectional debridement should be expeditiously performed using the finger fracture technique, argon bean, or CUSA. Anatomical liver resection for trauma is rarely required and often has a poor outcome, especially if done for hemorrhage control. This procedure is performed in fewer than 10% of patients (1, 33) and is associated with 50–67% mortality.(33, 37, 38)

Inflow Occlusion

Vascular isolation of the liver should be sequentially applied if packing fails to sufficiently control hemorrhage. Digital or instrumental clamping of the hepatoduodenal ligament (Pringle maneuver) should be attempted first. This maneuver can be quickly performed either with pinching the portal triad between the thumb and forefinger or with the application of an atraumatic vascular clamp. Although controversy exists over how long the portal triad of a trauma patient can remain clamped, most surgeons agree that the Pringle maneuver can be applied safely for at least 30–60 minutes before ischemic damage occurs.(1)

The Pringle maneuver can also be diagnostic. If it slows or stop bleeding, one can assume an arterial source or bleeding from a portal venous branch. If the liver has been packed and the Pringle maneuver is required to stop the bleeding, one can assume that it is arterial in nature as it is assumed that the packing would have minimized venous bleeding. In this case, finger fracture can be used to identify the injured arterial vessel for clipping or suture ligation. Alternatively, hepatic artery isolation and ligation can be performed to determine if right or left hepatic ligation is necessary. Most trauma surgeons agree that the ligation of the hepatic artery either surgically or with angio-embolization pre- or postoperatively is well tolerated if the portal venous blood supply is intact.(1, 15)

If the Pringle maneuver fails to stop the bleeding, hemorrhage from lacerated hepatic vein or hepatic venous tributary should be considered, and total vascular isolation should be attempted, as described below.

Hepatic Veins/ Retrohepatic Inferior Vena Cava Injuries

Hepatic vein and juxtahepatic IVC injuries are rare and still result in a very high mortality, ranging from 60 to 80%.(31, 33, 37, 39, 40) Most patients with these types of injuries present in arrest or near arrest and therefore diagnosis is exclusively made intraoperatively. (31) Indications for possible IVC or hepatic vein injury include dark blood or clot in the triangular ligaments, dark bleeding from behind the liver, and failure of the Pringle maneuver to control bleeding.(31) The following options are available to treat these grave conditions:

Total Hepatic Vascular Isolation

Total vascular occlusion of the liver can be performed to staunch blood flow temporarily and allow the surgeon to identify and directly ligate and/or repair hepatic vein or retrohepatic IVC injury in a relatively bloodless field. Nevertheless, this procedure is technically demanding and often not tolerated well by the patient.

The first step in total vascular isolation is aortic clamping, either in the supraceliac abdominal aorta or in the descending thoracic aorta just above the diaphragm. This limits arterial inflow to the liver, which prevents massive bowel congestion, and preserves flow to the brain and heart. Next, Pringle Maneuver is performed, followed by the occlusion of the suprarenal IVC and then the suprahepatic IVC.

Atriocaval Shunt

Atriocaval or Shrock shunt, first described in 1968, is placed in the vena cava either from a venotomy in the infrarenal IVC or from an incision made in the right atrial appendage. The shunt allows blood flow to return from the renal veins and infrarenal IVC into the right atrium, bypassing the supra-renal IVC and liver. When performed with the Pringle maneuver, the shunt allows for near total isolation of the liver and juxtahepatic IVC, as there are very

few tributaries into the IVC between the renal veins and right atrium (right adrenal, inferior phrenic).(39)

The first documented survivor of atriocaval shunting was reported in 1970.(39) Results ever since have been less than encouraging with mortality ranging from 78 to 90% in most series (33, 39, 41) with worse results observed in patients with penetrating trauma.(42) It should be noted, however, that all series of this type of injury have very small sample sizes, and firm conclusions cannot be drawn.(41)

Advocates of the atriocaval shunt argue that the high mortality associated with this procedure results from its use only after all other maneuvers to control bleeding have failed. At that point, acidosis, hypothermia, coagulopathy, and massive blood transfusion significantly increase mortality. Thus, it is indeed possible that the application of the atriocaval shunt as early as possible after the diagnosis of hepatic vein or retrohepatic IVC injury has been established would increase survival.

Veno-venous Bypass
Veno-venous bypass is another way to achieve vascular isolation of the liver. Again, a Pringle maneuver is performed. The suprarenal and suprahepatic IVC above the hepatic veins are also clamped or occluded. The liver is then bypassed by placing a femoral venous catheter to drain the renal veins and infrarenal IVC. This line is primed and connected to another central venous catheter in the internal jugular vein after being warmed by the bypass machine, thus completing venous return to the heart while bypassing the liver. This is a technically challenging procedure and requires the immediate availability of a cardiopulmonary bypass machine and an experienced perfusionist.(34)

Liver Transplantation
Liver transplantation for trauma is a rare occurrence, as most mechanisms leading to liver injuries severe enough to require transplantation cause profound systemic derangements and critical damage to other organs.(43) Since transplantation can be considered only in patients without other serious injuries and coagulopathy (1) and because there must be a suitable donor organ available almost immediately, only a handful of cases were published. For example, a recent series reported eight liver transplants done for uncontrollable hemorrhage or massive hepatic necrosis.(44) Of the eight recipients, three died after transplant, three died waiting for transplant, and two survived.

Liver transplantation can be done as either a one- or a two-step process. The one-step procedure involves explantation and transplantation in the same session. In the two-step approach, the injured liver is removed and a portocaval shunt placed. This is followed after a variable short period of anhepatic time by transplantation.

Other Tricks
Several new approaches to managing severe liver injury were recently proposed. For example, temporary control of massive bleeding by clamping a specific injury-containing area was described as a damage control approach.(45) In this maneuver, the clamps are left in place and the abdomen is temporarily closed. Thirty-six hours later, after adequate resuscitation, the patient

returns to the operating room for clamp removal, resection of the necrotic segment, and oversewing of the edges of the liver at the clamp site. If needed, interventional radiology techniques can be applied after surgery to further control bleeding or bile leaks.

Novel techniques were also described for the management of retrohepatic IVC injuries. These include the use of covered stent grafts placed via femoral cannulation into the retrohepatic IVC.(1) Such an approach eliminates the need for the very difficult and extensive IVC dissections to gain proximal and distal control. Another report described the use of endovascular balloons, placed via the internal jugular and femoral veins, to gain proximal and distal control of a juxtahepatic IVC injury.(42) In this case, fluoroscopy is used to guide the balloon catheters into the IVC and palpation over the IVC is used to position the balloons just proximal and distal to the site of injury. This vascular isolation technique allows the identification and repair of such injuries with minimal dissection and no release of retrohepatic or suprahepatic hematomas. A final trick that sometime helps diffuse superficial and intrahepatic bleeding is to take down the ligaments, wrap the liver with some absorbable material, and use a sterile ace wrap to compress the liver to stop the bleeding. The absorbable material helps when unwrapping the liver during the second operation.

> The patient was prepped and draped and a midline incision was made; upon entering the abdominal cavity, a moderate sized hematoma was evacuated from the right upper quadrant. Laparotomy pads were placed above and below the right lobe of the liver tamponading the damaged lobe. A brief abdominal survey revealed no evidence of hollow viscous injury and a small stable pelvic hematoma on the left. After determining that there were no other intra-abdominal injuries, the packs were removed from the right upper quadrant, the falciform and right triangular ligaments were taken down, revealing a laceration in the right lobe of the liver with a small amount of necrotic tissue along the inferior edge and oozing from the raw surface within the laceration. Finger fracture technique was used to open the laceration to the liver edge, allowing inspection of the entire raw surface within the laceration; several small vessels were occluded with suture ligation with excellent hemostasis; the small area of necrotic liver edge was resected using finger fracture technique. The raw liver surfaces were treated with topical hemostatic, and the laceration was closed with large chromic mattress sutures using a large blunt liver needle. Care was taken not to crush the tissue to prevent further ischemia. The closed laceration on the surface of the liver was also treated with application of a topical hemostatic. Drains were left in the right upper quadrant. The abdomen was then closed.

Factor VII
Recombinant activated factor VII (rFVIIa) is the hemostatic agent used for bleeding episodes in patients with hemophilia A or B. Off-label use of rFVIIa for coagulopathy in the trauma population has been studied for a number of years. A multi-institutional, randomized, placebo controlled trial in 2002–2003 found a significant decrease in the amount of packed red blood cell transfusions

and a trend toward improved morbidity and mortality without any evidence of increased risk of thromboembolic events.(46)

Specific clinical data on the efficacy of rFVIIa in the management of blunt liver injuries are lacking in the adult population. Nevertheless, a few case reports in pediatric patients have shown possible improved outcomes with arrest of worsening anemia and fewer blood transfusions. A 2007 study of eight children who received rFVIIa after blunt trauma with solid organ injury and dropping hemoglobin revealed no need for operative or angiographic intervention, and only 4 units of red blood cells were needed in three patients after rFVIIa administration.(47) Experimentally, the majority of studies failed to show decreased mortality in animals subjected to liver injury and rFVIIa treatment (48), although some groups reported decreased hemorrhage volume and reduced transfusion requirements.

At this point, rFVIIa may be indicated for coagulopathic bleeding in the blunt trauma patient, but no Class 1 data supporting specific use in patients with liver injuries are available.

Bed Rest
In the past, patients were advised to avoid strenuous activity and contact sports for at least 3–6 months after injury.(7) Nevertheless, newer studies using follow-up CT scanning showed resolution of 93% of injuries by 3 months. Furthermore, animal studies of liver injury documented normal or better tensile strength by the third post-injury week.(1, 5, 7, 49) Thus, most surgeons now advocate a period of 4–8 weeks during which strenuous or dangerous activities such as contact sports are avoided.(5, 7, 49) If return to work or recreational activities is desired sooner, follow-up CT scans can be performed to look for resolution of injury.

Follow-Up Computerized Tomography (Indicated? When?)
Most Grade I–III injuries resolve quickly, some even before patient discharge from the hospital. Follow-up CT studies in patients with these low-grade injuries demonstrated that CT imaging did not affect management or outcome, and therefore concluded that no follow-up imaging is necessary for this population.(7, 50) One exception could be very active individuals involved in contact sports. In these individuals, it is important to confirm complete resolution of injury before resumption of full physical activity.

The role of CT scanning in the follow-up of patients with Grades IV and V liver injuries is more controversial. Many studies showed that routine follow-up CT scanning fails to identify clinically significant injuries or complications requiring intervention unless the patient first demonstrated new symptoms.(1) For these injuries, follow-up CT scan should be performed only for clinical indications such as fever, leukocytosis, abdominal pain, and jaundice.(1, 7)On the other hand, others believe that some complications including pseudoaneurysms formation can occur with minimal or no symptomatology and therefore recommend routine follow-up CT imaging 6–8 weeks after injury. In the acute setting, repeat CT scanning should be performed only in the presence of progressive anemia, significant abdominal distention, or hemodynamic instability.

Patients with an operatively treated Grade III–V liver injury have a high rate of complications (up to 50%, 51). Therefore, routine postoperative CT scans may be useful in detecting fluid collections (bilomas, abscesses), pseudoaneurysms, and arterial–venous fistulae early. This allows for intervention before these complications become symptomatic. Indeed, follow-up CT scans in this patient population identified a significant number of complications in asymptomatic patients, 50% of which required intervention.(51)

Postoperatively the patient reported much improved abdominal pain. She was extubated and was able to recall the accident and complain of pain in her hip, leg, and arm. On postoperative day 3, her hemoglobin remained normal, and she was taken to the operating room by orthopedics for repair of her fractures. Postoperatively, the patient reported improvement in the pain of her extremities. She was slowly progressed to a diet and began working with physical therapy to improve mobility. Daily hemoglobin levels and chemistries revealed stable mild anemia and normal liver function. Because of the severity of the injury and the high risk of postoperative complications after liver surgery, a repeat CT scan of her abdomen was performed on hospital day 7, 5 days after her liver surgery. The CT scan revealed a small area of hematoma/necrosis with the liver parenchyma of the right lobe around the surgically repaired laceration. No areas of bleeding or intra-abdominal fluid collections were noted. The previously placed coils were noted, with no evidence of further flow in the pseudoaneurysm.

COMPLICATIONS OF LIVER TRAUMA AND THEIR MANAGEMENT
The incidence and severity of complications from liver trauma are dependent on the degree and management of the injury. Rates of complications related to nonoperative management of blunt liver trauma range from 0 to 12% (1, 5, 18, 21, 26, 52), while the rates for operative management range from 11 to 50%.(18, 38) The incidence of complications increases from 11% in Grades I–III injuries to 21% in Grade IV injuries and 63% in Grade V injuries (52)

Risk factors for the development of complications include Grade V injury, coagulopathy, increased fluid requirement, and increased number of transfusions.(38, 1) Common complications include abscess formation, hemobilia, re-bleeding, and biloma.

Abscess
Infection or abscess formation occurs in 0–1.5% of nonoperatively managed patients (4, 53) and in 9–12% of operatively treated individuals.(4, 21) Symptoms include fever, pain, feeding intolerance, and tachycardia. They usually appear several days after injury and are associated with elevated white cell count.(53) Diagnosis is established by ultrasound or CT scan. Most abscesses can be treated with percutaneous drainage and antibiotics, and fluid cultures from the abscess cavity usually contain mixed flora.(53) Patients with large fluid collections associated with systemic inflammatory response syndrome (SIRS) and hyperbilirubinemia may have infected bilomas, which may be amendable to percutaneous, laparoscopic (54), or surgical drainage.

Hemobilia

Parenchymal liver injury, especially from penetrating trauma, can cause fistulous connections between the bile ducts and the hepatic vasculature. A duct-to-artery connection may result in the decompression of high-pressured blood into the low pressure biliary tree, a phenomenon termed hemobilia. This occurs in 0.2–3% of liver injuries and may present with hemoptysis, coffee ground emesis, pain, and jaundice.(7, 25, 55, 56) This classic combination of symptoms occurs in only 30–50% of patients with hemobilia, and most patients are diagnosed based on CT scan findings after they present with pain or upper GI bleed.(55) Presentation is often delayed and definitive diagnosis and treatment are established by hepatic angio-embolization. Risk factors for development of hemobilia include large biloma and biliary fistula.(1, 25)

Fistulous connections between the ducts and hepatic veins can also occur. In this case, both systems are low-pressured, and bile diffuses passively into the serum leading to jaundice without elevated liver enzymes. ERCP with sphincterotomy or stenting is the usual mode of treatment for this condition.(6, 56)

Bile Leak and Biloma

Bile leak or biloma formation can also complicate the course of the liver injured patient. Occurrence ranges from 0.5 to 20% (1, 5, 7, 21, 54, 56), and incidence is slightly higher in operatively compared to nonoperatively managed patients.(1, 25) Complication rates also depend on how aggressive the surveillance is. Studies which used routine postoperative CT scanning in all moderate to severe liver injuries found higher rates of bilomas. Nevertheless, many of these collections were asymptomatic and most (70%) resolved spontaneously.(1, 7, 56) Routine HIDA scan also has a higher rate of detecting biliary leak, but again, the majority of asymptomatic patients resolved spontaneously.(1)

Symptomatic patients with fever, leukocytosis, pain, jaundice, or feeding intolerance are best treated with minimally invasive techniques.(1, 7, 21, 52, 56) CT- or ultrasound-guided percutaneous drainage should be attempted first and carry a very high success rate. ERCP with sphincterotomy or stent placement is effective in treating persistent bile leak.(1, 21) Infected bilomas should be promptly drained percutaneously, laparoscopically, or surgically.(54, 57)

> After the CT scan was performed, the patient was moved to an inpatient rehabilitation floor for continued treatment with physical therapy for her multiple fractures. One week after her surgery, her drains which had been putting out serous fluid began putting out greenish/brown bile, approximately 30–60 ml daily. Serial chemistries revealed no elevation of her liver function tests, and she demonstrated no evidence of sepsis. The patient underwent a HIDA scan which revealed a small leak from the lacerated liver edge. The patient continued to be observed on the rehabilitation floor and the drains were left in place. After another week of conservative management, the drainage cleared and became minimal and serous. Repeat HIDA scan showed resolution of the bile leak. The drains were removed and she was discharged to follow up with outpatient physical therapy and given an appointment to see the trauma surgery team in clinic.

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11 Blunt splenic injury

Amy D Wyrzykowski and David V Feliciano

An 18-year-old football player presents to the emergency department after colliding with another player on the field. During the execution of a play, the patient's abdomen was impacted by another player's knee. There was no loss of consciousness, but due to abdominal pain, he had to be carried off the field on a stretcher. Upon arrival in the emergency room, the patient is pale, diaphoretic, and clammy. He complains of left upper quadrant pain. Vital signs are notable for a heart rate of 110 bpm and a blood pressure of 90/50 mmHg. He is not in respiratory distress. The Glasgow Coma Scale (GCS) is 15 and he is neurologically intact.

On secondary survey, the patient is found to have tenderness to palpation in the left upper quadrant. The remainder of the exam is unremarkable. Admission chest X-ray (CXR) demonstrates elevation of the left hemidiaphragm. Pelvis film is negative. FAST demonstrates fluid in both the left paracolic gutter and splenorenal window. After the administration of 2 L of warm crystalloid, the patient has a heart rate of 95 bpm and a blood pressure of 120/80. Subsequent computed tomography (CT) scan of the abdomen and pelvis demonstrates the presence of a Grade IV splenic laceration with active contrast extravasation. He remains hemodynamically stable and is taken to interventional radiology where he undergoes an uneventful embolization of a segmental splenic vessel.

Following the procedure, he is admitted to the intensive care unit (ICU) for hemodynamic monitoring and serial evaluation of hemoglobin and hematocrit. Initially, the patient does well, remaining hemodynamically stable with a stable hemoglobin. However, on hospital day 3, he becomes acutely hypotensive and tachycardic. He fails to respond to the transfusion of 3 units of packed red blood cells (PRBCs) and is brought emergently to the operating room where he undergoes an exploratory laparotomy. Attempts at splenic salvage are unsuccessful and a splenectomy is performed. The patient has an uneventful recovery following the splenectomy. He receives the appropriate immunizations and is discharged to home.

IMMEDIATE MANAGEMENT

Initial care of the injured patient should follow the guidelines set forth by the American College of Surgeons Committee on Trauma as outlined in the *Advanced Trauma Life Support Course—the "ABCs" of trauma care*.(1) The patient's airway is patent, and his breathing is unlabored. He is, however, hemodynamically unstable at the time of presentation and in Class II hemorrhagic shock. He requires the prompt administration of a warmed crystalloid solution through two 14 or 16 gauge peripheral intravenous lines. The response to fluid should be carefully monitored by following hemodynamic parameters as well as urine output. He has no neurologic disability, and complete exposure fails to reveal any overt signs of trauma.

The patient responds to the administration of 2 L of crystalloid, and the blood pressure and pulse return to within normal parameters.

Demographics

Historically, the spleen has been the most commonly injured solid viscus in patients who have been victims of blunt trauma; however, this predated the development of CT. With the widespread use of CT scans, it is now apparent that both the liver and spleen are injured with similar frequency.(2)

The management of blunt trauma to the spleen has undergone a significant evolution over the past several decades. At one time, the spleen was sacrificed with relative impunity. The impetus to attempt splenic salvage was increased knowledge about the risk of developing overwhelming postsplenectomy infection, especially in the pediatric population.(3–5) For this reason and because the pediatric spleen generally has a thicker capsule and firmer parenchyma than that of the adult, nonoperative management was being employed in hemodynamically stable infants and children and operative splenic salvage was being widely employed in pediatric trauma before similar attempts were made in the adult population.

ANATOMY

The spleen is located deep within the left upper quadrant and is intimately associated with the left hemidiaphragm, the left lower ribs, stomach, tail of the pancreas, left kidney and left adrenal gland, distal transverse colon, and splenic flexure. Ligaments of varying density attach the spleen to surrounding structures. These include the splenophrenic ligament, splenorenal ligament, and splenocolic ligament. These fixed points render the spleen susceptible to injury, particularly in the setting of high-energy deceleration. Due to the anatomic relationships, common associated injuries include lacerations of the left hemidiaphragm, injuries to the tail of the pancreas and left renal hematomas and lacerations.(2)

The vascular supply to the spleen is relatively consistent. The predominant arterial supply is from the celiac axis via the splenic artery which divides into several vessels at or near the hilum creating a segmental blood supply to the spleen. Short gastric vessels arising from the left gastroepiploic artery also contribute. Venous drainage parallels arterial supply. Several segmental splenic veins coalesce to form a single splenic vein that joins the superior mesenteric vein. There are also various short gastric veins that empty into the left gastroepiploic vein.(2)

DIAGNOSIS

Physical Examination

Care should be taken to evaluate for any abrasions, ecchymoses or contusions that may suggest significant truncal trauma. The

abdominal examination in patients with blunt splenic injury may range from entirely benign to peritonitis depending on the degree of hemoperitoneum and the presence of associated injuries. Clearly, frank peritonitis is an indication for immediate laparotomy and does not require any additional evaluation. The lower ribs (9–12) should be palpated to elicit subtle tenderness consistent with rib fractures that may cause laceration of the underlying spleen.

Laboratory Evaluation

No laboratory blood test is diagnostic of a blunt splenic injury. It is prudent to obtain a type and crossmatch in any patient suspected of having significant intra-abdominal trauma. Additionally, a base deficit may also be useful to help guide resuscitation, serve as an indicator of occult injury, and predict both resource utilization and outcome.(6–9)

Imaging

Focused Assessment for the Sonographic Examination of the Trauma patient

Since first described by Rozycki et al., the Focused Assessment for the Sonographic examination of the Trauma patient (FAST) has become the accepted primary modality for imaging most patients with possible truncal trauma.(10) In fact, the most recent version of the *Advanced Trauma Life Support (ATLS)* manual considers the FAST as an adjunct to the primary survey.(1) The study involves an ultrasound (US) examination of four areas including the pericardial sac, right upper quadrant, left upper quadrant and pelvis, and can be easily learned. The FAST is rapid, noninvasive, and can readily be performed at the bedside. It is easily reproducible and can be performed serially to evaluate for changes.(10, 11) Overall, reported sensitivities for the study range 81–98% for the detection of intra-abdominal injury.(10, 12–15) In hypotensive patients with blunt trauma to the abdomen, the FAST exam has a sensitivity of 100% and a specificity of 99.3%.(16)

McKenney et al. described a hemoperitoneum score following a retrospective analysis of 400 positive US examinations. To determine the score, the anterior to posterior depth of the largest collection of fluid is first measured to the nearest 10th of a centimeter. Then, a point is added for each additional area positive for fluid. For example, a patient with a 2.2-cm deep fluid collection in Morison's pouch as well as fluid in the pelvis would have a score of 3.2. The authors found that an US score greater than or equal to 3 was predictive of a therapeutic operation. They subsequently prospectively validated the scoring system and determined that the majority (87%) of patients with an US score >3 required a therapeutic laparotomy. The hemoperitoneum score was found to be a better predictor of therapeutic laparotomy than either initial blood pressure or base deficit.(17) Independent of the hemoperitoneum score, any hemodynamically unstable patient with a positive FAST should be brought emergently to the operating room for exploratory laparotomy.

Diagnostic Peritoneal Lavage

If an US is not available or the treating physician is uncomfortable with the technology, diagnostic peritoneal lavage (DPL) remains

Table 11.1 AAST Spleen Injury Scale (1994 Version).

Grade[a]	Injury	Description
I	Hematoma	Subcapsular, nonexpanding, < 10% surface area
	Laceration	Capsular tear, nonbleeding, < 1 cm parenchymal depth
II	Hematoma	Subcapsular, nonexpanding, 10–50% surface area; intraparenchymal, nonexpanding, < 5 cm in diameter
	Laceration	Capsular tear, active bleeding; 1–3 cm parenchymal depth that does not involve a trabecular vessel
III	Hematoma	Subcapsular, >50% surface area or expanding; ruptured subcapsular hematoma with active bleeding; intraparenchymal hematoma> 5 cm or expanding
	Laceration	>3 cm parenchymal depth or involving trabecular vessels
IV	Hematoma	Ruptured intraparenchymal hematoma with active bleeding
	Laceration	Laceration involving segmental or hilar vessels producing major devascularization (>25% of spleen)
V	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury which devascularizes spleen

an option to evaluate the presence of intra-abdominal fluid. The reported sensitivity of DPL ranges 92–98%. Although it is invasive, complications can be decreased by using the open technique for insertion of the catheter. Limitations of the DPL are that it is invasive, nonspecific, cannot be reproduced and, like the FAST, does not adequately evaluate the retroperitoneum.(18)

Computed Tomography

The role of CT is explicitly limited to the evaluation of hemodynamically *stable* patients following blunt abdominal trauma. CT scan has a sensitivity of 92–98% as well as a specificity as high as 99%, which is significantly higher than with either FAST or DPL.(18, 19) Since CT is expensive, time-consuming, and delivers a not insignificant radiation dose, many centers have developed protocols for it, only when screening tests are positive.(18)

A hemodynamically stable patient with a positive FAST should undergo a CT scan of the abdomen and pelvis to determine the likely source of the hemoperitoneum. Solid organ injuries are graded based on the CT scan according to the American Association for the Surgery of Trauma (AAST) Organ Injury Scaling (OIS) System which was originally published in 1989.(20) The 1994 revisions (Table 11.1) are currently used in grading injuries to the spleen.(21)

The AAST OIS splenic injury grade does not include the presence of a "blush" or contrast extravasation which some authors have related to the failure of nonoperative management.(22, 23) The significance of a "blush" remains a source of controversy in the literature. In comparing CT to angiography, some authors have noted that CT can fail to demonstrate extravasation which is then seen on angiography. This scenario calls into question the sensitivity of a CT scan for the detection of active bleeding and the role of CT in predicting which patients will successfully undergo nonoperative management.(24) Although an intraparencyhmal contrast blush on CT scan is not an absolute indication for intervention,
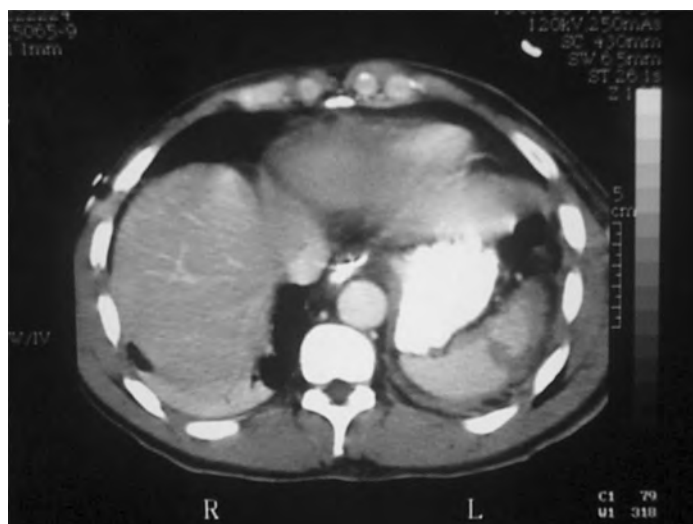
Figure 11.1 AAST OIS Grade II splenic laceration.

Figure 11.2 AAST OIS Grade IV splenic laceration. Note the involvement of the hilar vessels.

it does probably warrant angiography to determine if the patient might benefit from angioembolization.(25) A blush in a hemodynamically unstable patient mandates immediate operation.

> The patient responds to volume resuscitation in the trauma bay and is subsequently hemodynamically stable. On further evaluation the FAST is positive for free fluid in the abdomen. As the patient remains stable and does not have peritonitis on physical examination, it is appropriate to pursue additional imaging with a CT to determine the source of the intraperitoneal fluid and grade the lesion. Given the "blush" on CT scan, angioembolization is performed.

MANAGEMENT

Nonoperative Management

Observation

The most important criteria for consideration of nonoperative management are hemodynamic stability and lack of another indication for laparotomy. Unstable patients with a positive FAST or DPL and patients with peritonitis belong in the operating room. Patients undergoing nonoperative management of a blunt splenic injury should be admitted, be closely monitored, and undergo both serial abdominal exams and laboratory assessment of hemoglobin and hematocrit. Hemodynamic parameters must also be closely monitored. The majority (82%) of failures of nonoperative management occur within the first 72 h of hospitalization; (4) patients, therefore, must be closely monitored for at least 3 days. Some authors have suggested that the majority of patients with blunt splenic injury do not need inpatient monitoring after 3 days. (26) Patients with significant underlying medical conditions that may predispose to failure of nonoperative management such as cirrhosis and human immunodeficiency virus (HIV) should probably be monitored longer.(26) The need for bed rest in patients with known blunt solid organ injuries is unclear. A recent large

retrospective review found that the timing of mobilization does not impact delayed splenic rupture and concluded that protocols requiring strict periods of bed rest are unnecessary.(27)

It is recommended by some authors that patients with a Grade III or greater splenic injury undergo repeat imaging prior to discharge (See figures 11.1 and 11.2). The time for healing of a splenic injury varies by severity of injury. Patients with Grade I or II injuries heal on average at 12.5 days. In patients with a more severe injury (Grade III and above), the average time to healing is 37.2 days, and 80% of patients have documented healing by 75 days.(28) It is, therefore, prudent to recommend avoidance of strenuous activity and contact sports for 2 to 3 months following nonoperative management of a severe splenic injury.

The development of peritonitis and/or hemodynamic instability indicates that nonoperative management of the injured spleen has failed. There is no clearly defined amount of blood transfusion that mandates laparotomy; however, one study found that patients in whom nonoperative therapy failed received a mean of 2.4 units of blood per patient as compared to 0.54 units in those managed without surgery.(5) If a patient has received 2 units and has a need for additional transfusion, consideration should be given to proceeding to laparotomy.

The failure rate of nonoperative management of blunt splenic trauma in appropriately selected adults is 6–10%.(4, 5, 29) Careful selection of patients being considered for nonoperative management is critical, and the selection criteria have changed significantly over the past three decades. For example, when blunt splenic trauma was first being managed nonoperatively in the adult population, one of the absolute contraindications was the presence of a neurologic abnormality such as a traumatic brain injury that presumably would prevent the clinician from accurately diagnosing the development of peritonitis. Archer et al. however, demonstrated that there were no significant differences in mortality, morbidity, or failure of nonoperative management when comparing patients with and without an impaired neurologic exam.(30)

In a large multi-institutional study, Pietzman et al. (4) found that the most common indications for operation in patients who failed

nonoperative management were decreasing hematocrit, change in CT scan, and abdominal pain. They also noted that the AAST grade of splenic injury correlated with the need for delayed operative intervention. Failure of nonoperative management increased progressively with grade of injury. For example, whereas only 4.8% of patients with Grade I injury underwent laparotomy, 75% of patients with Grade V injuries failed nonoperative management. The same authors also found that the degree of hemoperitoneum was an independent predictor of the need for operative intervention. Successful nonoperative management was employed in 80.1% of patients with a mild hemoperitoneum, 50.6% of patients with a moderate hemoperitoneum, but in only 27.4% of patients with a large hemoperitoneum.(4) Other predictors of success included high blood pressure and hematocrit and less severe injury based on Injury Severity Score (ISS) and GCS. While it has been noted that patients 55 years and older have higher rates of failure of nonoperative management, age alone is not an absolute contraindication to nonoperative management.(32, 33) In summary, predictors of failed nonoperative management include advancing grade of injury, active contrast "blush" on CT scan, hemoperitoneum score, hypotension, increasing ISS, lower GCS, and age greater than 55 years.

Angioembolization
Angioembolization is a useful adjunct in the nonoperative management of blunt splenic injury in the hemodynamically stable patient. The primary objective is to preserve the function of the spleen by avoiding splenectomy. Active extravasation of contrast on a CT scan has been identified as a sign of vascular injury, ongoing bleeding and a predictor of failure of nonoperative management.(21, 22) Embolization is a safe, effective way to stop active hemorrhage in hemodynamically stable patients (34, 35) and is noted in various reports to improve the success rate of nonoperative management.(34–37) Complications following embolization include splenic abscesses and bleeding. These complications, however, do not seem to affect patient outcome.(38)

Angioembolization can be technically accomplished by proximal embolization of the main splenic artery or selective, segmental embolization. Proximal embolization provides hemostasis by decreasing perfusion pressure to the spleen. By occluding the splenic artery, the entire spleen is rendered relatively ischemic and is subsequently perfused only by various small branches arising from the left gastroepiploic artery. While this technique is effective in controlling hemorrhage and increases the success of nonoperative management, the magnitude of the effect on splenic function is not entirely clear. Patients treated with proximal embolization may face the same impaired immune response and infectious complications as those who have undergone splenectomy because of loss of the filtering function of the spleen.(39) One study found higher rates of sepsis and acute respiratory distress syndrome (ARDS) in patients having an embolization of the proximal splenic artery as compared to those undergoing a splenectomy.(39) In contrast, in a small retrospective study, Bessoud et al. (40) concluded that embolization of the proximal splenic artery does not have a major impact on the immune function of the spleen. Additional studies in this area are needed. Selective segmental embolization theoretically avoids these issues and should probably be utilized when feasible.

The indications for splenic angioembolization have been debated in the literature. Whereas some authors advocate admission angioembolization on all patients with splenic injuries, others suggest screening criteria that should be used to determine which patients undergo the procedure. Haan et al. (41) performed admission celiac angiography on all stable patients admitted with a documented splenic injury on CT scan. The average grade of injury in their study was almost Grade III, and patients with high grade injuries were included. The authors' analysis determined that screening angiography and embolization as indicated can improve nonoperative salvage rates to 92% even when considering high-grade lesions.(41) Screening every patient with a splenic injury with an angiogram is very labor-intensive and not feasible at the majority of centers providing care to injured patients.

An alternative approach is to perform angiography selectively based on admission CT findings. In one study, extravasation of splenic vascular contrast ("blush") or the presence of a focal intrasplenic vascular abnormality such as a posttraumatic pseudoaneurysm or arteriovenous fistula had an overall sensitivity of 81% and an accuracy of 83% in predicting the need for splenic angiography and subsequent endovascular therapy or surgery.(42) Other trauma centers have used contrast blush, pseudoaneurysm, large hemoperitoneum, or Grade IV or V injuries as indications for angiography with good outcomes and a splenic salvage rate as high as 98.2%.(43, 44) It is, therefore, recommended that hemodynamically stable patients with evidence of contrast extravasation on CT scan or other vascular lesion undergo angiography with selective embolization if feasible. It is also reasonable to consider angiography in patients with high-grade splenic injuries who are being considered for nonoperative management.

Operative Management
As previously noted, a hemodynamically unstable patient with evidence of blood in the peritoneal cavity on FAST or CT scan or a grossly positive DPL belongs in the operating room. In the hemodynamically stable patient, indications for operation include persistent acidosis, more than 2 units of blood transfusion, and the development of peritonitis.(35) As for all trauma patients, the patient's skin should be widely prepared and draped. An exploratory laparotomy is performed through a generous midline incision. Given the anatomical relationships, it is important to evaluate a patient with a splenic injury for associated injuries to the left hemidiaphragm, left adrenal gland, left kidney, distal transverse colon, splenic flexure, and pancreas. It must be remembered that the tail of the pancreas is intimately associated with the splenic hilum, and care must be taken to avoid an iatrogenic injury to the pancreas when operating on the spleen. The spleen is mobilized into the wound via medial traction and the sharp division of the splenophrenic, splenorenal, and splenocolic ligaments. In the hemodynamically stable patient, several short gastric arteries are sequentially ligated to facilitate mobilization. In the unstable patient, the spleen can be bluntly mobilized into the midline in a matter of seconds. Once the spleen is mobilized, the magnitude of injury is determined and a decision is made to proceed with either splenorrhaphy or splenectomy.

The theoretical advantages of splenorrhaphy and avoidance of splenectomy include preservation of the varied immunologic

Table 11.2 Techniques for Splenorrhaphy.

Topical agents
Gelfoam, Surgicel, Avitene, Tisseal, Collastat
Fibrin glue
Electrocautery
Bovie electrocautery
Argon beam coagulator
Suture Splenorrhaphy
Continuous or horizontal mattress
Adjuncts: omental plug, pledgets
Meshes
Absorbable—vicryl mesh
Nonabsorbable—Teflon
Partial or Hemisplectomy
Segmental vessel ligations, resection, mattress sutures
Stapler

Source: Ref (3).

functions of the spleen, avoiding the risk of overwhelming post-splenectomy infection (OPSI), and averting the postoperative complications of splenectomy such as a left subphrenic fluid collection or abscess. In patients with AAST Grade I and II injuries such as small lacerations and capsular avulsions, application of a topical hemostatic agent and pressure are usually all that is required. More complex injuries require more complex intervention. A list of techniques for splenorrhaphy is provided in Table 11.2.

Suture splenorrhaphy is best suited for superficial or moderately deep lacerations and can be accomplished using either a continuous suture or interrupted technique with horizontal mattress sutures. The visible parenchyma should be inspected for bleeding vessels, and selective ligation may need to be performed before oversewing the laceration. Sutures commonly used in the repair of splenic lacerations include 2–0 or 3–0 chromic or polypropylene. If the capsule tears when the stitches are tied, one can consider the use of pledgets. Alternatively, an omental pedicle can be placed on the injured area and used as a buttress when tying the sutures. Another option is to wrap the spleen in an absorbable mesh such as polyglycolic acid. The mesh can be used to bring together gaping lacerations and exert a tamponade effect.(3)

For more significant injuries, a partial splenectomy may be employed. As noted previously, the main splenic artery branches as it approaches the hilum of the spleen and then further divides creating a segmental blood supply and rendering the spleen amenable to a segmental resection. This technique is best applied when the injury is at one pole of the spleen. To perform a partial splenectomy, the arterial branch to the affected portion of the spleen is ligated. The spleen then demarcates, and the demarcated component is removed with either a knife or electrocautery. Selective ligation or electrocautery is then performed on the resulting raw edge, while complete hemostasis is obtained by inserting vertical mattress sutures to bring the exposed edges together.(3)

If the patient has ongoing blood loss, need for transfusion, or hemodynamic instability in spite of attempted splenorrhaphy, splenic salvage should be abandoned and splenectomy should be performed. As the spleen is already mobilized, this can be accomplished expeditiously. It is generally prudent to individually suture ligate both the splenic artery and vein. Prior to closing, one should

inspect again for associated injuries. Particular care should be taken to be sure that the short gastric vessels have been ligated as failure to do so can result in a return to the operating room. In the absence of an associated injury to the pancreas or kidney, there is no indication for the placement of a drain following splenectomy.

There are a few case reports describing the use of laparoscopy for both splenic salvage and splenectomy in patients following blunt splenic trauma.(45–47) While these techniques have been employed successfully, they should not be considered the standard of care in the management of trauma patients.

Postoperative care
In the absence of other injuries mandating admission to the ICU, most patients undergoing splenectomy can be safely managed on the surgical floor. Diet can be advanced as the ileus resolves.

Asplenic patients have a much greater risk of infection from encapsulated organisms—*Pneumococcus*, *Meningococcus*, and *Haemophilus influenzae Type B (Hib)* than the general population. Thus, all patients undergoing a splenectomy should be vaccinated for these pathogens. Specifically, patients should receive the 23-valent pneumococcal polysaccharide vaccine, the meningococcal vaccine, and the *Hib* vaccine. In patients undergoing elective splenectomies for hematologic disorders, these vaccines should be given 2 weeks prior to splenectomy. Patients undergoing an emergency splenectomy should receive the vaccines 2 weeks postoperatively to allow for an optimal immunologic response.(48) Revaccination with pneumococcal vaccine is recommended at 5 years after the initial administration.(49, 50) Given the poor rate of follow-up in some trauma centers, it is probably wise to give the vaccines prior to discharge, even if this occurs less than 2 weeks postoperatively. This avoids the problem of a patient receiving no vaccinations at all should he or she fail to return for a scheduled follow-up visit to the clinic. Patients must also be educated about the risk of overwhelming postsplenectomy infection.

> The patient undergoes angioembolization which is appropriate given the hemodynamic stability and findings of a Grade IV laceration and "blush" on CT scan. High-grade injuries are more likely to fail at attempts to nonoperative management, and this patient's lesion places him at risk of failure. While repeat angioembolization can be entertained in the stable patient, this young man becomes hemodynamically unstable mandating laparotomy. Attempts at splenic salvage are abandoned in the face of ongoing blood loss and the patient undergoes an uncomplicated splenectomy. The patient receives the appropriate vaccinations postoperatively.

COMPLICATIONS

Complications of Operative Management

Overwhelming postsplenectomy infection
OPSI has been a recognized entity since the 1800s.(48) It can occur anytime following splenectomy from the immediate postoperative period to decades later, but is extremely rare. One study documented a mortality rate of OPSI of 0.03% per 100 person-years of exposure.

(51, 52) OPSI is devastating—death prevails in over half of the documented cases and usually within 24 h.(48) The syndrome presents with fever associated with a brief upper respiratory tract infection and rapidly progresses to shock, disseminated intravascular coagulation, and multiple system organ failure. The causative organism is *Pneumococcus* in over 60% of cases.(51) Treatment is largely supportive, but should include antibiotics effective against the encapsulated bacteria. Prevention is of great importance—appropriate vaccinations, as described earlier, patient education, and follow-up are critical.

Complications of Nonoperative Management

Splenic artery pseudoaneurysm

The development of a splenic artery pseudoaneurysm is a rare complication of the nonoperative management of splenic trauma. The natural history of the lesion is unknown, but it is thought to be a potential mechanism for delayed hemorrhage. When a pseudoaneurysm adjacent to the splenic capsule is identified, the patient should be treated with angioembolization of the lesion. If this is not feasible, splenectomy or splenorrhaphy should be considered.(53)

Splenic pseudocyst

Only about 800 patients with splenic pseudocysts that are not parasitic in nature have been reported in the literature. It appears that the incidence has risen slightly over the preceding two decades. The etiology of the increase is thought to be the increased nonoperative management of splenic injuries and the widespread use of imaging for evaluation of even vague complaints. The cysts are likely the result of encapsulation of a traumatic subcapsular hematoma in which the pigment is eventually reabsorbed and serous fluid remains. The cysts are asymptomatic in 30–60% of patients. Symptomatic individuals present with left upper quadrant pain followed by the development of nausea and emesis secondary to gastric compression. The diagnosis can be established with a CT finding of splenic cyst in the appropriate clinical setting. The treatment is either splenectomy or resection of the area containing the cyst and splenorrhaphy. Other options include percutaneous drainage and laparoscopic fenestration of the lesion; however, these latter two techniques are associated with unacceptably high failure rates.(54)

Splenic abscess

Splenic abcesses from a hematogenous or contiguous source may also develop following nonoperative management of the injured spleen. The source may be hematogenous or contiguous. Patients present with left upper quadrant pain and fever, and most will also have an elevated white blood cell count. Patients are usually treated with splenectomy though percutaneous drainage is also an option.(53)

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12 Penetrating renal injuries
Rao R Ivatury

A 44-year-old man is admitted following a shooting accident while deer hunting. He is awake and alert, and his vital signs are normal. On secondary survey, there is a 2-cm gunshot wound (GSW) in the right flank, and his abdomen is tender and distended. A Foley catheter is inserted with return of bloody urine. The patient is rushed to the operating room and a large right perinephric hematoma is noted on exploration.

OPERATIVE APPROACH

Retroperitoneal Hematoma

The operative approach to nonpulsatile nonexpanding retroperitoneal hematomas in penetrating trauma is controversial.(1–6) Immediate exploration of all such hematomas has been recommended by several authors. For example, a prospective study of 50 patients with 53 renal injuries (43 GSW and 7 SW) who underwent laparotomy and routine exploration reported that excluding three OR deaths, routine renal exploration lead to simple drainage in 13 (26.5%), renal repair in 17 (35%), partial nephrectomy in 6 (12%), and nephrectomy in 13 (26.5%). The authors recommended routine renal exploration. Armenakas et al. (7) analyzed a 20-year experience with 199 patients with 200 renal injuries from stab wounds. Nonoperative treatment was selected in 108 patients (54%). The other 92 renal injuries were explored. Seventy four were reconstructed (80.4%), and 11 required nephrectomy (12%) for an overall renal salvage rate of 94.5%. These authors suggested that meticulous attention to reconstructive techniques in renal exploration can ensure an excellent renal salvage rate.

Several studies (2–6), however, have shown that in patients with penetrating renal injury, a selective approach can be safely implemented in hemodynamically stable patients. Several prerequisites are important for this practice. First, one must ascertain that the hematoma is truly a Zone II (lateral) hematoma that is perinephric, in contrast to Zone I (mid-line) hematomas. All Zone I hematomas need to be explored to rule out major abdominal vascular injuries. (8) Second, the perinephric retroperitoneal hematoma must be nonexpanding and stable on continued observation. There must be no suspicion of a renal pedicle injury, which may be suggested by continued hemorrhage or a large hematoma in the midline, or urinary extravasation. If there is any suspicion of a pedicle or hilar injury, these structures can be explored without violating the integrity of the Gerota's capsule and preserving the tamponade effect of the intact capsule. If the exploration is negative and the hematoma is stable, the perinephric hematoma may be left unexplored.

Gunshot wounds to the kidney, especially from high-velocity missiles or close-range shotguns, may have an increased risk of delayed complications because of extensive tissue damage. Low-velocity GSW and knife or stab injuries, according to current opinion, may have a selective exploration of the hematoma, as long as the conditions described above are met.(2–5) In one series (9), 52 consecutive patients with renal GSW renal injuries were explored only if they involved the hilum or were accompanied by signs of continued bleeding. Thirty-two patients underwent renal exploration and 17 of them required nephrectomy for major renovascular or high-grade parenchymal injuries. Renal exploration was successfully avoided in the remaining 20 patients. The authors concluded that mandatory exploration of all gunshot wounds to the kidney was not necessary. Even in the presence of multiorgan injuries in the abdomen, selective exploration of the kidneys may be successful. In one series (10), in the absence of an expanding hematoma and/or hemodynamic instability, associated injuries by themselves did not increase the risk of nephrectomy. Despite multiorgan penetrating injuries, 54% of kidneys were salvaged.

In the present case, the size of the retroperitoneal hematoma was noted to increase during the first 15 minutes of the operation and the hematoma appeared not to be confined to the Gerota's fascia. Thus, it was decided to explore the lateral retroperitoneal hematoma.

Early Vascular Control

Vascular control of the renal hilum should be considered before opening a perinephric hematoma. The transperitoneal approach (Figures 12.1 and 12.2) has the advantage of avoiding catastrophic bleeding that may ensue when the Gerota's fascia is opened and its tamponade effect is lost. Preliminary control of the renal pedicle will facilitate a more elective assessment of injury and salvage of the kidney by repair or partial resection. Nephrectomy rates have been reduced by this maneuver from 56% to 18% in one series. (11) On the other hand, a Level 1 study, which randomized patients with penetrating renal injuries to early vascular control or direct exploration of the kidney, reported a similar nephrectomy rate in both groups.(12) Since the need for vascular control cannot always be identified before entering the perinephric hematoma, some authors recommend it for all patients. However, this is not universally accepted. If the perinephric hematoma is continuous with a large central retroperitoneal hematoma, supraceliac control of the aorta can be pursued, as described somewhere else in this book.

Intraoperative One-Shot IVP

Before performing a nephrectomy in stable patients with penetrating renal trauma, it is mandatory to perform an intraoperative one-shot pyelogram. This study, performed by a rapid bolus administration of contrast and a plain abdominal film, will confirm the existence of a contralateral functioning kidney. Its use for detecting urine extravasation or ureteral injuries is very limited. Alternatively, methylene blue or indigo carmine can be injected intravenously after occlusion of the ureter on the injured
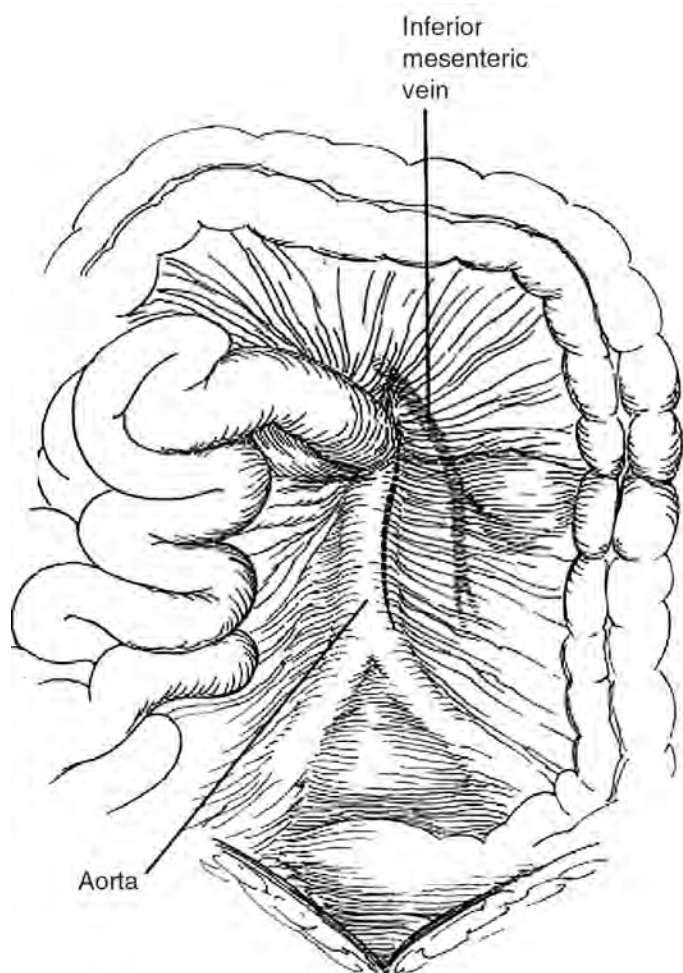
Figure 12.1 Early vascular control by incising the peritoneum medial to the inferior mesenteric vein.
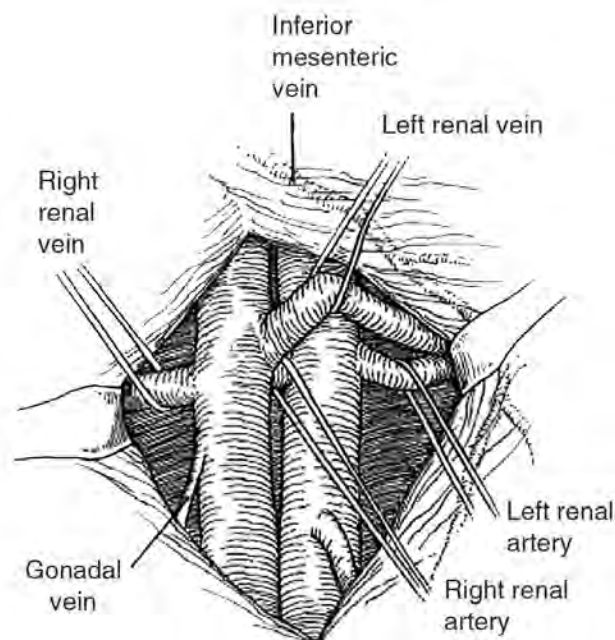
Source: Armenakas NA.(30)

Figure 12.2 Blunt dissection will expose the renal pedicle and facilitate vascular control.

Source: Armenakas NA.(30)

side. Appearance of dye color in the urine would confirm the presence of a functioning contralateral kidney. If the patient is hemodynamically unstable and a rapid nephrectomy is indicated for hemorrhage control, the presence of a contralateral kidney is surmised by palpation.(2–5)

Renal Reconstruction

Renal salvage can be accomplished by a variety of techniques (Figures 12.3 and 12.4). The first step is a complete exposure of the kidney by entering the fascia and compressing the organ to staunch bleeding. If vascular isolation had not been done previously, the pedicle may be controlled by atraumatic vascular clamps to reduce bleeding and facilitate the assessment of the injury. All nonviable tissue is debrided, and bleeding vessels are ligated under vision. If the collecting system is lacerated, the defects are closed with nonabsorbable sutures in a watertight repair. The parenchyma of the kidney is then repaired by buttressing with omentum or renal capsule.(2–5) Absorbable meshes made of polyglycolic acid (Dexon® or Vicryl®) are useful alternatives. "Wrap" techniques with mesh either as a "cap" at one pole after a partial nephrectomy or around the entire kidney when there are multiple lacerations were also reported.(13)

Nephrectomy

The nephrectomy rate for immediate exploration of major renal lacerations varies depending on the type and severity of the trauma and hemodynamic instability. Penetrating mechanism, high-velocity weapons, and multiple injuries are associated with a higher nephrectomy rate.(2–5)

In one series (14), 69 of 87 renal injuries were surgically explored (79.3%), and 12 patients underwent nephrectomy (13.8%). Forty-six (66.6%) renal units were reconstructed by various methods, including renorrhaphy, omental pedicle flaps, mesh or peritoneal patch grafts, partial nephrectomy, and vascular repair. The overall renal salvage was 86.2%. Early renal vascular control was achieved in all patients who underwent renal exploration. These findings suggest that early vascular control and careful selection of reconstructive techniques can ensure a high renal salvage rate in patients with high-grade renal gunshot injuries.

Renovascular and Renal Pedicle Injury

Avulsed or lacerated vessels usually mandate renal exploration to control hemorrhage with either ligation of the artery, with or without nephrectomy, or repair of the vessel.(15–18) The success of arterial reconstruction is related to the duration and degree of ischemia and presence or absence of accessory renal arteries providing collateral flow. With a warm renal ischemia time of >2 h, irreversible damage ensues.(2–5) Nephrectomy may be required in 67%–86% of patients with main renal artery injuries and in 25%–56% of those with main renal vein injuries. The kidney may be spared in segmental vessel injuries alone. Injuries
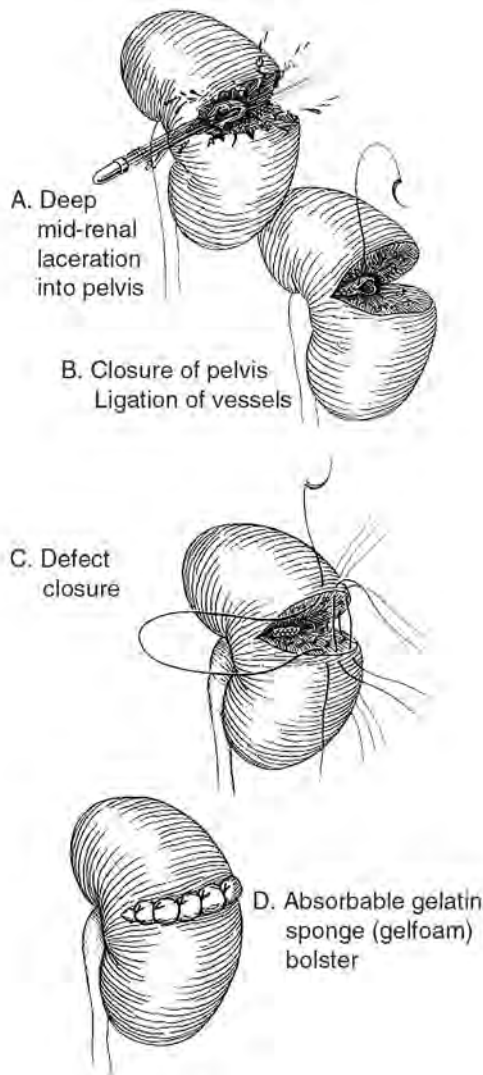
A. Deep
mid-renal
laceration
into pelvis

B. Closure of pelvis
Ligation of vessels

C. Defect
closure

D. Absorbable gelatin
sponge (gelfoam)
bolster

Figure 12 3 Methods of renal repair. Omentum, absorbable mesh may also be used as bolsters.

Source: Armenakas NA.(30)

Table 12.1 The AAST Organ Injury Severity Scale.

I	Contusion: Microscopic or gross hematuria, urological studies normal
	Hematoma: Subcapsular, not expanding with no parenchymal laceration
II	Hematoma: Not expanding, perirenal hematoma confined to renal retroperitoneum
	Laceration: <1.0 cm parenchymal depth of renal cortex with no urinary extravasation
III	Laceration: >1.0 cm parenchymal depth of renal cortex with no collecting system rupture or urinary extravasation
IV	Laceration: Parenchymal laceration extending through renal cortex, medulla, and collecting system
	Vascular: Main renal artery or vein injury with contained hemorrhage
V	Laceration: Completely shattered kidney, vascular avulsion of renal hilum which devascularizes kidney
	Advance one grade for bilateral injuries up to Grade III.

to the left renal vein near the vena cava can be managed with ligation, as adequate venous drainage will be provided by the gonadal and adrenal veins. Injuries to the main renal vein on the right must be repaired, and this is usually achieved with a lateral venorrhaphy. Autografting with the inferior mesenteric, hypogastric, or splenic artery has occasionally been reported with limited success. Autotransplantation or removal of the kidney and bench surgery before reimplantation, on occasion, may be necessary in the treatment of an injury to a solitary kidney. (2–5) A multicenter study from the Western Trauma Association documented the poor outcomes from renovascular injuries.(15) Arterial repairs had significantly worse outcomes than venous repairs. Neither the time to definitive surgery nor the operating surgeon's specialty significantly affected outcome. In this series, 15 had immediate nephrectomy, 1 had a renal artery repair, and 1 had a bypass graft.

Grading Renal Injuries
Renal injury scale, described by the AAST, is given in Table 12.1. Several retrospective and prospective studies validated this scale.

A. Partial polar
nephrectomy

B. Collecting system
closure

C. Omental pedicle flap
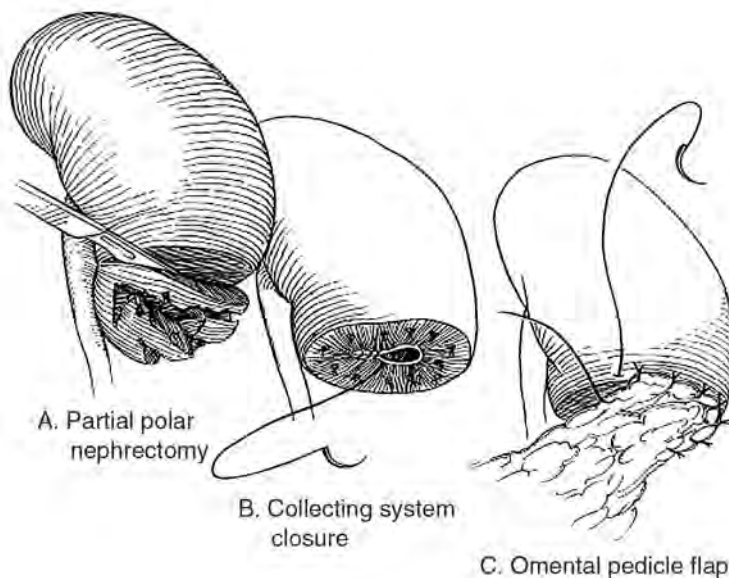
Figure12.4 Technique of partial nephrectomy.

Source: Armenakas NA.(30)

In a series of 424 patients with traumatic renal injury, the majority were of Grades I and II. Systolic blood pressure and hematocrit levels decreased, and blood transfusions and hospital length of stay increased with increasing AAST grades. The mechanism of injury and the AAST scale were the sole predictors of nephrectomy.(21) Santucci et al. (22) analyzed a large database retrospectively and observed that the AAST grades correlated with the need for surgery in an escalating pattern: 0, 15, 76, 78, and 93% for Grades I–V. These grades also correlated with the need for nephrectomy.

NON-OPERATIVE APPROACH

In the absence of the usual indications for exploratory laparotomy (hemodynamic instability, the presence of a large perirenal hematoma with contrast extravasation, ureteral injury, or renal pelvis injury), many centers successfully employ nonoperative treatment.(2–7, 23) The definition of renal injury with CT scan and the demonstration of the tract of the wounding agent are some of the criteria that favor such an approach. The other important consideration is to rule out associated intra-abdominal injuries that may require exploration and repair. This is particularly applicable to gunshot wounds of the abdomen. Nonoperative therapy must be based on a careful consideration of the trajectory, hemodynamic stability, absence of diffuse peritoneal signs, and, most importantly, CT evaluation to rule out intraperitoneal injuries.(24)

Angio-embolization is increasingly advocated in stable patients with CT findings of contrast extravasation from vascular injuries. Success rates for embolization of isolated renal artery branch injuries with surgical gelatin, steel coils, or autologous clot are 70–80%.(2–5, 19–20) The future may see an increasing application for angiographic techniques even in more severe renovascular injuries, especially when the patient is hemodynamically stable and there is no urgent indication for operative exploration.

In the presented case, the renal pedicle was explored first. The vessels were isolated and found to be intact. Vascular clamps were applied on both artery and vein, and the Gerota's fascia opened. A large complex injury with active bleeding was identified in the lower pole of the kidney. Partial nephrectomy was performed and two large J-P drains placed. It should be noted that the presence of a right renal vein or distal left renal vein injury would necessitate either a repair (if the patient's condition allows) or a nephrectomy. A left renal vein injury proximal to the gonadal veins can be treated by ligation. Arterial injuries would require a repair if the warm ischemic time is short and if the patient is stable. If the warm ischemic time is long and/or the patient is unstable, a nephrectomy would be indicated.

Complications

Urinary extravasation associated with major renal lacerations will resolve spontaneously in 80%–90% of patients. When a collection forms, the resultant urinoma is often asymptomatic but may cause abdominal or flank discomfort, a palpable mass, an

Table 12.2 Indications for Renal Exploration and Levels of Supporting Evidence.

1	Hemodynamic instability, presumably from renal injury	Level 1B
2	Renal pedicle avulsion (Grade V injury)	Level 1B
3	Expanding, pulsatile, or uncontained retroperitoneal hematoma	Level 1B
4	A large laceration of the renal pelvis, or avulsion of the uretero-pelvic junction (PUJ)	Level 1B
2	Coexisting bowel or pancreatic injuries	Level 1B
3	Persistent urinary leakage, postinjury urinoma, or perinephric abscess with failed percutaneous or endoscopic management	Level 1C
4	Complete renal artery thrombosis of both kidneys, or of a solitary kidney	Level 1C
5	Abnormal intraoperative one-shot intravenous urogram (IVU)	Level 2C
6	Devitalized parenchymal segment with associated urine leak	Level 2C
7	Renal vascular injuries after failed angiographic management	Level 2C
8	Renovascular hypertension	Level 2C

Source: Santucci RA.(29)

adynamic ileus or low-grade fever.(2) It may get infected to form a perinephric abscess. CT will establish the diagnosis, and percutaneous catheter drainage of the collection is often successful. Persistent urinary leak may occasionally need diversion by a retrograde ureteric stenting.(25, 25) Infected urinomas are now initially managed with percutaneous drainage with good results. Delayed or secondary hemorrhage is a common complication of deep lacerations of the renal cortex and medulla, probably secondary to an arteriovenous fistula (AVF) or pseudo-aneurysm. If persistent and significant, angiography will establish the causative factor and provide nonoperative management by angiographic embolization.(2–5) Posttraumatic renal hypertension (26–28) is related to excess renin secretion caused by renal ischemia and may be a result of renal arterial thrombosis or injury. The risk of renovascular hypertension following both observation and repair varies widely. Clark et al. (27) reported 113 conservatively managed blunt renovascular injury patients, where 27% developed hypertension with 21% requiring delayed nephrectomy. However, others (28) have reported only about a 6% rate of hypertension after nonoperative management.

SUMMARY

Penetrating renal injuries, especially from knives and low-velocity gunshots, are best managed by a consideration of the hemodynamic status of the patient. Unstable patients need to be surgically explored. The decision to explore the kidney depends on the operative findings. The literature-derived recommendations and the levels of evidence are summarized in Table 12.2, adapted from the consensus statement from World Health Organization and the Societé Internationale d'Urologie.(2) Optimal salvage of renal tissue and outcomes for these patients may be achieved by a careful consideration of these principles and the application of angiographic techniques in carefully selected patients.

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13 Blunt pancreaticoduodenal injury
Nasim Ahmed and Jerome J Vernick

A 40-year-old male restrained driver is brought to the trauma center following a head-on motor vehicle collision. His initial complaint is epigastric pain. On primary survey, airway is patent; breath sounds are equal bilaterally; O$_2$ saturation is 100% on room air; and blood pressure and heart rate are 125/82 mmHg and 90 bpm, respectively. The patient's Glasgow Coma Scale (GCS) is 15 and he is moving all four extremities. Secondary survey reveals a seat belt mark across the chest and mid-abdomen as well as epigastric tenderness. Chest and pelvic radiographs are normal but computed tomography (CT) scan shows a 2.5-cm laceration at the neck of the pancreas with peripancreatic fluid. Emergent endoscopic retrograde cholangiopancreatography (ERCP) reveals transection of the main pancreatic duct at the neck of the pancreas. The patient is therefore taken to the operating room for exploratory laparotomy. On exploration, a large retroperitoneal hematoma is noted in the lesser sac. Further dissection identifies edematous pancreas partially transected at its neck. The main pancreatic duct is noted to be transected as well. Spleen-preserving distal pancreatectomy is performed and a Jackson-Pratt drain is placed adjacent to the stump. Postoperatively, the patient has persistent fever (38.5°C) and leukocytosis (15,000). The drain output is 75 ml/day and its amylase level is 100. On postoperative day 7, an abdominal CT is performed, which demonstrates a lesser sac abscess. As the patient continues to be febrile, a CT-guided percutaneous drainage of the abscess is performed.

IMMEDIATE MANAGEMENT

Based on the CT scan findings, pancreatic duct injury was suspected. As the location and severity of injury play a role in deciding whether to pursue nonoperative or operative approach as well as dictate the surgical procedure of choice, it is advisable in stable patients to delineate the injury by pre- or intraoperative pancreatography. This can be done by ERCP, which can also be utilized for therapeutic stenting of the severed pancreatic duct. This is particularly efficacious in proximal rather than distal duct injury. (1) Alternatively, magnetic resonance cholangiopancreatography (MRCP) can be performed although its sensitivity and specificity are relatively low in the acute injury situation.

PANCREATIC INJURY

Demographics

Blunt pancreatic injuries are relatively rare (5% incidence) due to the retroperitoneal location of this organ.(2–5) The usual mechanism of pancreatic injury is compression of the abdomen against the vertebral column by seat belts, steering wheel, or a direct blow. Pancreatic injuries are often associated with other intra-abdominal injuries, which contribute to the high morbidity and mortality. Associated injuries include splenic tears or hematomas, duodenal perforation or intramural hematoma, and spine fractures with or without cord compression. Other high-energy deceleration injuries such as mesenteric avulsion and aortic tears should be considered as well.

Diagnosis

Physical Examination

Initial abdominal findings may be subtle but often evolve over several hours. Surface abrasions, contusions, ecchymosis, and hematomas are nonspecific but could be indicative of potential underlying damage. Guarding and tenderness are helpful when present but may be masked by distracting injuries or diminished level of consciousness. As physical findings are inaccurate in diagnosing pancreatic injuries, imaging by Focused Assessment for the Sonography of Trauma (FAST) exam and/or CT scanning are indicated as soon as the patient's condition allows.

Blood Tests

Laboratory tests including serum amylase levels are neither sensitive nor specific. Normal serum amylase levels do not exclude ductal injury (6, 7) although rising serial determinations can raise the index of suspicion for significant injury.

CT Scan

Preoperative contrast-enhanced CT scan is the imaging study of choice with sensitivity up to 85%, although injury grading for ductal injury is correct in only less than 50% of patients.(1, 8, 9, 10, 11) Peripancreatic hematoma, thickening of Gerota's fascia, and fluid in the lesser sac are typical indicators of pancreatic injury often visible on high-quality CT scans (Figures 13.1 and 13.2).

ERCP is the procedure of choice for a hemodynamically stable patient with suspected pancreatic ductal injury. Extravasation of contrast from the duct localizes and quantifies the injury (12, Figure 13.3). Recently, ERCP has also been used therapeutically for stenting of mainly proximal ductal injuries.(1) A negative ERCP provides a level of comfort when clinical issues favor avoidance of an urgent laparotomy.

MRCP is a noninvasive imaging modality for acute pancreatic injuries. Nevertheless, its use did not gain popularity since it carries a lower sensitivity than the ERCP.(3) Dynamic secretin-stimulated magnetic resonance cholangiopancreatography (DSSMRCP) can delineate the ductal injury as well as illustrate the entire pancreas.(13) Unfortunately, this modality has limited application in the acute setting.

Figure 13.1 Reveal transaction at the neck of the pancreas and splenic injury.
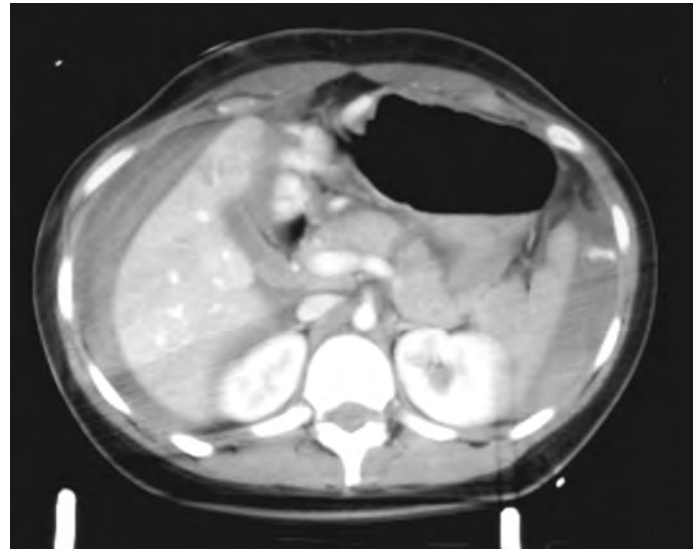

Figure 13.2 Pancreatic transaction at the neck.

The presented patient undergoes abdominal CT followed by ERCP. This diagnostic modality is selected because the patient is hemodynaically stable and the CT scan suggests a 2.5-cm laceration in the neck of pancreas. In the absence of other indications for laparotomy, a negative ERCP or minor extravasation amenable to stenting would have avoided an operation. However, ERCP demonstrates that the pancreatic duct is severed, which prompts an emergent surgical intervention. Distal pancreatectomy with splenic sparing is possible in this stable patient whose pancreatic injury is diagnosed promptly. If the patient has been hemodynamically unstable or if delayed operation would have demonstrated significant local inflammatory changes, distal pancreatectomy with splenectomy should have been performed.

Management

Intraoperative Evaluation of Pancreatic Duct Injury
Direct visualization and palpation of the pancreas at laparotomy is necessary for accurate identification of pancreatic injuries. Exposure of the pancreas can be obtained by dividing the gastrocolic ligament and retracting the stomach cephalad. A Kocher maneuver allows bimanual palpation of the head of the pancreas and duodenum. Obvious laceration to the pancreas or complete transaction of the pancreas at the head, body, or neck is indicative of major duct injury. In general, duct injury will not be present in the absence of parenchymal disruption. Some ductal injuries may not be visible and require further testing. Administration of secretin (1 unit/kg body weight, i.v.) can demonstrate clear fluid secretion from the severed duct. Alternately, intraoperative ultrasound (US) (14) or intraoperative pancreatography can be very useful.(11)

Without Ductal Injury (Grade I and II)
Minor contusions seen on CT scan (Grade I injury) can be managed nonoperatively.(11, 15, 16) However, any suspicion of ductal injury requires ERCP evaluation. Change in serial abdominal examination and/or continued rising serum amylase level require repeat CT scan or operative intervention.

Major contusions (Grade II) without ductal injury require simple drainage. Frequently, Grade I and II injuries can cause necrosis at the edge of the contusion site, requiring debridement and placement of an omental patch over the laceration and drainage. Drains should be kept in place until minimal output is seen with full enteral feedings.(17)

With Ductal Injury (Grade III)
Pancreatic injury with ductal disruption at the body or neck can be addressed by distal pancreatectomy. In the hemodynamically stable patient, a splenic preserving procedure can be performed.(11) In this case, it is important to assess the vascularity of the spleen, especially if the splenic artery and the short gastric vessels were divided for exposure. Collateral flow through an intact gastroduodenal artery is present but should be ascertained. Intraoperative Doppler is helpful if splenic inflow is questionable. However, the concept of splenic salvage may not be feasible in hemodynamically unstable patients.(15)

With Proximal or Severe Parenchymal injury (Grade IV)
Management of a pancreatic transaction to the right of the superior mesenteric vessels poses a challenge. A distal pancreatectomy in that situation requires almost 80% of the pancreas to be removed, resulting in hyperglycemia in the majority of the patients.(6, 11) Thus, central debridement or resection with distal pancreaticojejunostomy and Roux-en-Y reconstruction seems to be the method of choice. The first step of this technique is to separate the distal end from the remaining proximal pancreas. To minimize the risk of stump leakage, the proximal remnant should be oversewn and the duct should be identified (if possible) and ligated. Next, the distal end must be dissected up to 2–3 cm after separating the mesenteric and portal systems, and then the Roux-en-Y pancreatojejunostomy is performed. (11) A large closed system (i.e., 19 Fr Jackson-Pratt) drain should be placed in the area of the anastomosis for controlling a potential leak.

With Severe Injury (Grade V)
Severe injury to the head of the pancreas even with a high suspicion of ductal injury may require external drainage only, thus

Figure 13.3 ERCP showing extravasations of contrast from the severed pancreatic duct.

creating a controlled fistula. Endoscopic placement of a stent in proximal duct injury has also been reported in the literature.(1) Destructive pancreatic head injury associated with devitalization of the ampulla or severe proximal duct injury may require pancreaticoduodenectomy.(18)

Blunt trauma to the pancreas is relatively rare and is one of the most easily overlooked traumas. Delay in diagnosis leads to high morbidity.(19) Major early complications are pancreatitis, pancreatic abscess/necrosis, pancreatic fistula, and pseudocyst.

> The presented patient has partial transection at the neck of the pancreas with pancreatic duct injury. As he is hemodynamically stable and has no other injuries, the more time-consuming spleen-sparing distal pancreatectomy is performed.

Complications

Pancreatitis

Post-traumatic pancreatitis is a known complication of an unrecognized pancreatic duct injury. Typical clinical presentation consists of abdominal pain, nausea, and hyperamylasemia.

Although this condition usually resolves in a few weeks with conservative management (20), some patients develop persistent recurrent pancreatitis requiring surgical intervention. A recent report documented a 17% incidence of pancreatitis following trauma. Symptoms resolved within a few weeks in two-thirds of the patients, however, the remaining third required surgical intervention for recurrent episodes of pancreatitis.(20) Chronic recurrent pancreatitis may occur due to narrowing of the common bile duct in the retropancreatic region.(21) ERCP and stenting of the narrowed duct can alleviate the symptoms.

Pancreatic Abscess

Pancreatic abscess is a complication seen in 20% of patients with delayed diagnosis of pancreatic injury.(20, 22, 23) The development of a pancreatic abscess is not always related to the degree of pancreatic injury, but rather to an associated hollow viscus injury.(24) Treatment involves antibiotics and CT-guided external drainage.(23) Failure of percutaneous drainage mandates operative drainage.

Pancreatic Fistula

Pancreatic fistula develops in approximately 20% of patients with an isolated pancreatic injury and in 35% of those with combined pancreaticoduodenal injuries.(6, 23, 25)

The pancreatic fistula is considered a low-output fistula if the output is less than 200 ml/day and a high-output fistula if drainage is more than 500 ml/day.(26) Initial management of either a low- or high-output fistula should consist of nutritional support, control of infection, and adequate drainage. Nutritional support is provided by total parenteral nutrition (TPN), followed by enteral feeding when the output is less than 100 ml/day. However, if output increases with enteral feeding, it should be discontinued and TPN restarted. Persistent drainage beyond 500 ml/day for more than 1 week, could suggest a ductal injury, and an ERCP should be performed. If a ductal injury is identified, endoscopic stenting can be pursued.(26) The use of octreotide for reducing fistulous output remains controversial in the setting of a post-traumatic pancreatic fistula.(27, 28) Overall, 90% of the fistulae close within 8 weeks of conservative approach and only 10% require operative intervention—(29) distal pancreatectomy or Roux-en-Y pancreaticojejunostomy for distal and proximal leaks, respectively.

Pancreatic Pseudocyst

Pancreatic pseudocysts (Figure 13.4) develop due to unrecognized pancreatic ductal injuries, and present clinically weeks or months after the original injury.(30) Management depends upon the patient's symptomatology, the characteristics of the duct injury, and the maturity of the pseudocyst's wall.(31) Symptomatic patients with progressively enlarging pseudocyst should have an MRCP or ERCP to identify ductal injury. If the study demonstrates no communication of the main pancreatic duct to the pseudocyst, percutaneous CT- or US-guided drainage should be performed. Pseudocysts communicating with the main proximal pancreatic duct, can be drained endoscopically.(32) Endoscopic drainage should also be attempted if the pseudocyst is adherent to the stomach or duodenum and a bulge is identified during endoscopy.(33) Operative drainage by cyst-gastrostomy, cyst-duodenostomy, or Roux-en-Y cyst-jejunostomy is required when endoscopic drainage is not possible (30) or is repeatedly unsuccessful. Pseudocysts containing large quantities of solid

Figure 13.4 A pseudocyst in the head of the pancreas following one week of injury.

debris frequently require open intervention. Infected pseudocysts are best drained externally. This can be done with a cyst-gastrostomy which is, in turn, drained externally through a gastrostomy tube. The external tube is later removed and the inevitable fistula drains into the stomach where it causes no problem.

> The presented patient develops a pancreatic abscess, which is drained percutaneously. This approach is selected because it is less invasive and carries a high success rate. If percutaneous drainage of the abscess is not feasible or does not improve the patient's condition, an operative drainage should be attempted.

DUODENAL INJURY

Blunt duodenal injury is relatively rare and frequently difficult to diagnose. Delayed diagnosis will lead to increased morbidity and mortality.(34) No single preoperative diagnostic test and or management strategy is effective for all duodenal injuries. Blunt duodenal injury usually occurs following direct application of a significant force to the anterior abdomen, which crushes the duodenum against the spine: Nevertheless, duodenal injury can also develop at the junction of its fixed (retroperitoneal) or mobile (intraperitoneal) portions following deceleration. A high index of suspicion and close attention to the mechanism of injury play a key role in the diagnosis of injuries to the duodenum. Treatment depends upon the severity and location of the duodenal injury as well as associated injuries.

Diagnosis

Physical Exam

Nausea, vomiting, abdominal pain, and tenderness are the most common clinical signs and symptoms of patients with suspected duodenal injuries. These findings are nonspecific and may appear only later due to the retroperitoneal localization of the duodenum.

Blood Tests

A single serum amylase level in and of itself is not very sensitive for either a pancreatic or duodenal injury. Serial serum amylase
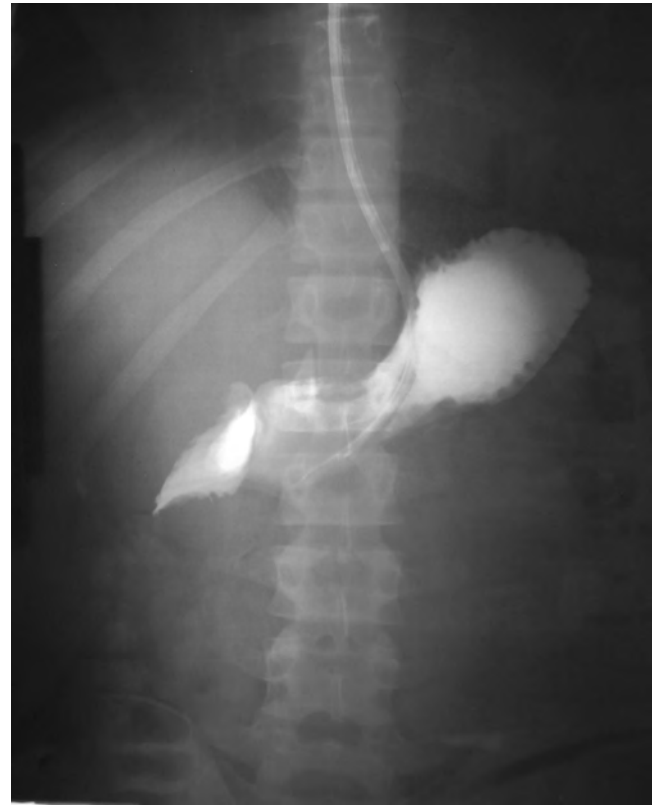
Figure 13.5 Contrast upper gastrointestinal tract showing duodenal hematoma.

determinations are useful to evaluate trends; a normal level does not exclude injury.(35–38)

Radiography

Flat plate of the abdomen: Plain radiography has a limited diagnostic role in the era of CT scanning. Nevertheless, a plain X-ray may show gas bubbles in the retroperitoneal space adjacent to the right psoas muscle and around the right kidney or free air under the diaphragm.(35, 39, 40)

Contrast study of upper gastrointestinal tract: Studies have demonstrated that this diagnostic modality has a specificity of 50% for duodenal perforation.(41) It has also been shown that the use of barium contrast has a higher sensitivity than gastrografin.(42) Extravasations of contrast is indicative of perforation and the classic "coiled spring" appearance suggests duodenal mural hematoma (43, 44) (Figure 13.5).

CT Scan

Abdominal CT is widely used for diagnosing intra-abdominal injuries. Its sensitivity for detecting duodenal injuries as well as associated injuries is very high, particularly in children.(42, 45, 46) Typical findings suggestive of a duodenal injury include extravasation, periduodenal edema or air, and duodenal wall thickening (Figures 13.6 and 13.7).

Management

Non-Operative

Intramural hematoma of the duodenum shown in CT scan or upper gastrointestinal imaging studies should be managed by

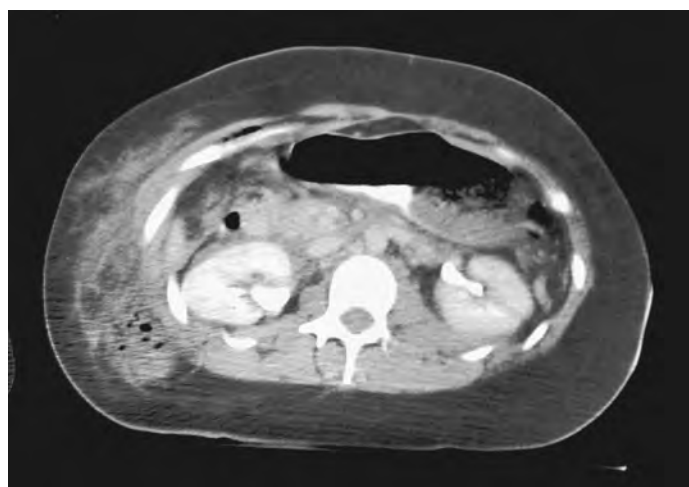Figure 13.6 CT scan shows intramural hematoma of the duodenum.

Figure 13.7 CT scan shows duodenal perforation with periduodenal air and subcutaneous emphysema.

conservative means using nasogastric (NG) decompression and parenteral nutrition for at least 3 weeks.(47, 48) Failure of this therapeutic paradigm requires operative intervention to rule out duodenal perforation as well as associated pancreatic injuries.

Operative

Approach and Identification of Injury   The retroperitoneal location of the duodenum renders diagnostic laparoscopy a limited role in the diagnosis of duodenal injury.(49) Surgical exploration should be pursued in cases with a high index of suspicion. Retroperitoneal bile staining or hematoma around the duodenum requires complete visualization of the duodenum to exclude injury. A Kocher maneuver (mobilizing the second and third part of the duodenum medially) and gaining exposure through the gastrocolic ligament allow the surgeon to appropriately visualize the second and third portion of the duodenum. Visualization of the fourth part of the duodenum requires division of the ligament of Trietz.(50) If no perforation is identified on inspection, methylene blue should be instilled through the NG tube and the periduodenal area must be inspected for blue staining.(51)

Duodenal Perforation   **Primary repair:** When the injury involves less than 50% of the circumference of the duodenum, primary repair is recommended. Closure of the perforation is usually done transversely.(52)

Serosal patch: If the primary repair of the defect would compromise the lumen, then the serosa of a jejunal loop is sutured to the margins of the perforation.(53) Although this is an effective procedure, leaks have been reported in the literature.(54)

Resection and anastomosis: With complete transaction of the first, third, and fourth portions of the duodenum, the surgeon should perform debridement of the edges, mobilization of the proximal and distal segments, and an end-to-end anastomosis.(39) If mobilization is difficult in the first part of the duodenum due to loss of tissue, then antrectomy, closure of the duodenal stump, and Billroth II gastrojejunostomy should be performed. End-to-side Roux-en-Y duodenojejunostomy should be completed when

mobilization is difficult and a tension-free anastomosis cannot be ascertained in third and fourth parts of the duodenum.(55)

A defect in the lateral wall of the second part of the duodenum can be repaired by direct Roux-en-Y jejunal loop. This method can also be applied to other areas of duodenal perforations when there is a larger defect.(50) All duodenal repairs need external drainage adjacent to the repair for early detection and control of a leak.(55)

Duodenal exclusion: The duodenum is the first part of the gastrointestinal tract and passes 6 l of enzyme-rich gastrointestinal content daily. Thus, any suture line leak can be catastrophic. It is therefore recommended that in high-risk patients with severe duodenal injury, the repair should be protected by duodenal diversion procedures. These include:

- *Triple tube decompression:* This technique, which was first described almost half a century ago (56), is comprised of gastrostomy to decompress the stomach, a retrograde jejunostomy to decompress the duodenum and an antegrade jejunostomy for feeding. However, recent studies did not show significant benefit of protecting the duodenorrhaphy.(39, 57) In patients with severe injury, placement of a feeding jejunostomy is highly recommended.(39)

- *Duodenal diverticulization:* Originally, this procedure consisted of closure of the duodenal wound, placement of a decompressive duodenostomy tube, distal gastrectomy, and a Billroth II reconstruction.(58) More recently, truncal vagotomy and placement of biliary drainage have been added to the procedure. This very extensive operation should be considered only in stable patients with significant tissue damage in the first and second parts of the duodenum (Figure 13.8). Pancreaticoduodenectomy may actually be a better choice if frequently done by the operating surgeon or an available colleague.

- *Pyloric exclusion:* This partially reversible procedure (Figure 13.9) was developed as a simpler alternative to the duodenal diverticulization. After a primary repair of the duodenum, a gastrotomy incision is made at the antrum along the greater curvature. The pylorus is then visualized and pulled through
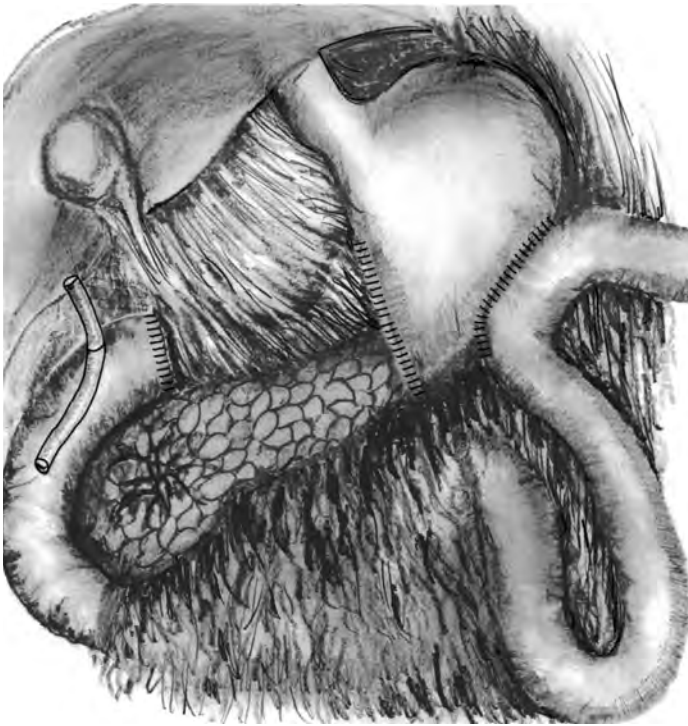
Figure 13.8 Depicting the duodenal diverticulization.

Figure 13.9 Showing steps of pyloric exclusion.

the gastrotomy and closed with either suture or staples, followed by gastrojejunostomy.(59) The pyloric channel usually reopens after several weeks regardless of whether it is sutured by absorbable or nonabsorbable suture or closed via a stapler. (60) An even faster modification of this technique includes postpyloric external stapling and a stapled gastrojejunostomy. Pyloric exclusion is relatively simple and faster to perform; however, recent studies have debated the outcome of the procedure in severe duodenal injuries.(61) Furthermore, a 10% rate of developing a marginal ulcer was reported following this procedure, which does not include vagotomy.

Duodenal Wall Hematoma

The management of duodenal intramural hematomas identified on laparotomy is controversial.(52) Some authors have suggested exploration of intramural hematomas through the serosa while leaving the mucosa intact. If no perforation is found, the hematoma is evacuated. However, the risk of converting a partial injury into a perforation prohibits most surgeons from using this approach.

Complications

Abdominal Abscess

Abdominal abscess occurs in up to 28% of patients with duodenal injury, and results from spillage of duodenal contents into the peritoneal or retroperitoneal spaces.(42, 62–64) Contamination occurs immediately following injury and evolves into infection, abscess formation, or severe inflammation unless the perforation is promptly diagnosed and treated.(65) Thus, retroperitoneal abscess is the main cause of mortality after duodenal injuries, especially in

the presence of continuous leakage of intestinal content and pancreatic enzymes. Nutritional support, appropriate antibiotics, and drainage of the abscess are the main courses of treatment.

Percutaneous drainage of a duodenal retroperitoneal abscess is often not adequate, and frequently the drainage tube becomes blocked by debris. Laparotomy, primary repair of the duodenum with or without pyloric exclusion, and drainage of the abscess have been described as management options.(42, 62, 64) However, inflammatory processes and adhesions may pose significant difficulty in performing these procedures. Alternatively, drainage can be successfully achieved through a retroperitoneal approach.(63, 66)

Enterocutanous Fistula

Fistulae arising from the duodenum after blunt abdominal trauma develop either due to delay in diagnosis or leakage following repair. This condition is very difficult to manage because it involves high outputs of enzyme-rich secretions.(67) Eighty percent of fistulae close with bowel rest, total parenteral nutrition, and control of infection or sepsis.(68) A number of surgical modalities are available for nonhealing fistulas, including pyloric exclusion, diverticulization, rectus abdominis flap, and cholecystojejunostomy.(65, 69)

Combined Pancreaticoduodenal Injury

The basic principles of managing combined pancreaticoduodenal injury are similar to those applied for isolated pancreatic injury; control of hemorrhage, and intestinal spillage. The following statements can be made:

1. Complete exposure of the duodenum and the entire pancreas are critical to successful management.(11)
2. Any hematoma and bile staining in the peripancreatic and/or retroperitoneal areas should be explored to identify the extent of the injury.
3. Management depends upon the patient's hemodynamic status, and extensive procedures should be avoided in unstable patients.(4, 17, 70)
4. It is crucial to identify the integrity of the common bile and pancreatic ducts, and ampulla, as well as the viability and location of the duodenal injury. If the injury is in the second part of the duodenum, a small probe such as a 23-ga Angiocath or 5-Fr infant feeding tube can be passed through the ampulla to identify the duct in relation to the injury.(71, 72) Cholangiogram via the gallbladder or the common bile duct is an alternative method to identify the ducts. Complete visualization of the common bile duct and free flow of contrast into the duodenum without extravasation suggest an intact common bile duct. If the injury is in the third or fourth part of the duodenum, duct integrity should be evaluated by a duodenotomy opposite to the ampulla or cholangiogram, as stated earlier.
5. Simple injury to the duodenum and mild to moderate injuries to the pancreas can be managed by primary repair and drainage, respectively. Severe injury to the duodenum and mild to moderate injury to the pancreas require the surgeon to perform complex procedures such as duodenal diverticulization, pyloric exclusion, triple tube decompression, or pancreaticoduodenectomy, as described earlier.

DAMAGE CONTROL IN PANCREATIC AND DUODENAL INJURIES

Hemodynamically unstable patients with a major injury to the second part of the duodenum along with an injury to the ampulla and head of the pancreas require a damage control approach. This approach, which is described in detail elsewhere in this book, allows the surgeon to stage the management and resuscitation of critically injured patients. This approach entails an initial speedy control of bleeding and bowel contamination followed by ligation of the common bile and pancreatic ducts. Further resuscitation is continued in the intensive care unit to optimize the patient's condition. Approximately 24–48 h later, the patient undergoes a second procedure where pancreaticoduodenectomy is completed.(73)

OUTCOMES OF PANCREATIC AND DUODENAL INJURIES

Pancreatic and duodenal injuries are uncommon and occasionally difficult to diagnose. Their association with other intra-abdominal and vascular injuries leads to high mortality and morbidity. The overall mortality of pancreatic and duodenal injuries is around 17%. However, it increases more than threefold when diagnosis is delayed for more than 24 h.(6, 35, 36, 57, 60, 74–78) Damage control surgery in hemodynamically unstable patients and staged procedures reduced the incidence of mortality and morbidity.(74)

Pancreatic and duodenal injuries often evolve into complex fistulae and collections, which require the involvement of expert pancreatic and hepatobiliary surgeons

Evidence-Based Analysis of the Management of Pancreatic and Duodenal Injuries Since pancreaticoduedenal injuries are rare, no Level I evidence is available. Most of the literatures are based on retrospective case series

Issue	Recommendation	Level of Evidence
CT diagnosis of pancreatic injury	CT is accurate in diagnosing pancreatic injury in two-third of cases (8, 9)	Level III
ERCP/MRCP diagnosis of pancreatic duct injury	ERCP is more sensitive than MRCP in diagnosing the pancreatic duct injury (3, 12)	Level III
Spleen-sparing distal pancreatectomy in Grade III pancreatic injury	Distal pancreatectomy without splenectomy has better outcome than distal pancreatectomy with splenectomy in stable patient (3)	Level III
Operative approach to severe duodenal injury	Pyloric exclusion is not necessary in all cases of severe duodenal injuries. Primary repair can be performed safely (61)	Level II
CT diagnosis of duodenal rupture	CT scan finding is often negative or nonspecific. Extravasations of contrast on CT scan is an uncommon finding (13%) of duodenal rupture (34, 46)	Level III
Pancreatic fistula after blunt trauma	Most traumatic pancreatic fistula can be managed nonoperatively (29)	Level II

American Association for the Surgery of Trauma (AAST) Classification of Pancreatic and Duodenal Injuries: (79) AAST Classification of Pancreatic Injury

Grade	Injury	Description
I	Hematoma	Minor contusion without duct injury
	Laceration	Superficial laceration without duct injury
II	Hematoma	Major contusion without duct injury or tissue loss

(Continued)

Grade	Injury	Description
	Laceration	Major laceration without duct injury or tissue loss
III	Laceration	Distal transaction or parenchymal injury with duct injury
IV	Laceration	Proximal (to the right of the superior mesenteric vein) transaction or parenchymal injury
V	Laceration	Massive disruption of pancreatic head

AAST classification of duodenal injury

Grade	Injury	Description
I	Hematoma	Involving a single portion of duodenum
	Laceration	Partial thickness, no perforation
II	Hematoma	Involving more than one portion of duodenum
	Laceration	Disruption <50% of circumference
III	Laceration	Disruption 50–75% of circumference D2
		Disruption 50–100% of circumference D1, D3, and D4
IV	Laceration	Disruption >75% of circumference D2, involving ampulla or distal common bile duct
V	Laceration	Massive disruption of duodenopancreatic complex
	Vascular	Devascularization of duodenum

D = duodenum; (1–4) = sections of the duodenum.

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14 Penetrating colon injury
Aaron Winnick and Patricia O'Neill

A 29-year-old female presented to the emergency room approximately 4 h after sustaining a single stab wound to the anterior abdomen. The patient initially stayed home but decided to seek medical help when her abdohal pain worsened. She was awake and alert on arrival with a respiratory rate of 18, a blood pressure of 115/80, and a heart rate of 110 bpm. On physical exam, she was noted to have a single stab wound to the anterior abdomen, 6 cm to the left of the umbilicus with tenderness localized to the left abdomen. Intravenous access was obtained, and the patient was administered tetanus toxoid intramusculary (IM) and given 2 g of cefoxitin intravenously. Abdominal wound exploration was performed and confirmed violation of the anterior abdominal fascia. The patient was therefore taken directly to the operating room.

On abdominal exploration, a 3 cm laceration was identified in the mid-descending colon, with a moderate amount of stool spillage into the peritoneal cavity. The laceration was repaired primarily with a two-layer handsewn technique, and the remainder of the abdomen was carefully inspected, but no other injuries were found. The abdomen was irrigated with 8 l of normal saline assuring that all blood and visible debris were removed. The fascia was re-approximated with running suture closure. The skin was left open and packed for a delayed primary closure.

The patient was extubated at the completion of the procedure and monitored in the Post Anesthesia Care Unit for the first several hours postoperatively. She remained stable and was subsequently transferred to the trauma ward. Cefoxitin was administered for 24 h postoperatively and then discontinued. The patient received daily dressing changes of her abdominal wound, and on postoperative day (POD) 4 a delayed primary closure was performed. Bowel function returned on POD 5, and she was started on oral diet, which was advanced as tolerated. On the same day, however, the patient developed a temperature of 100°F, and her white cell count increased to 16. Her abdominal wound appeared normal and she denied any symptom. It was decided to follow the patient expectantly. On the following day (POD 6), her white blood cell (WBC) increased to 18 and she developed a fever to 101°F with loss of appetite. She had no other signs or symptoms, and her abdominal wound remained without signs of infection. An intraabdominal abscess was suspected and an abdominal computed tomography (CT) scan was performed, which demonstrated a small pelvic fluid collection. The patient was started on intravenous Zosyn, and the abscess was drained percutaneously by the interventional radiologist. Three days later, cultures of the abscess fluid grew Escherichia coli and Enterobacter cloacae, which were sensitive to Zosyn. The patient's fever and WBC count normalized within the next 2 days. She completed her course of antibiotic therapy and was discharged from the hospital on POD 12.

PENETRATING COLON INJURIES: GENERAL OVERVIEW

Incidence and Etiology

The vast majority of all hollow viscus injuries result from penetrating trauma, whereas the incidence of such injuries in blunt trauma is very low.(1) Among those patients with hollow viscus injury from penetrating trauma, the incidence of colon injury is quite high. In one prospective series of 317 patients with hollow viscus injury from penetrating trauma, 162 patients (51%) sustained at least one colon injury while only 4.7% patients sustained duodenal injury, 20% gastric injury, and 36% small bowel injury.(2) In that series, 80% of the colon injuries were caused by gunshot wounds (GSWs) while only 20% were the result of stab wounds.(3)

Surgical Intervention

While all patients with penetrating abdominal trauma who present with hemodynamic instability and/or diffuse peritonitis should undergo an emergent celiotomy, the management of stable patients is selective and depends on the mechanism of injury.

As GSWs to the abdomen are associated with a high incidence of intraperitoneal injury, the traditional approach to this condition has been mandatory exploratory laparotomy in any patient with suspected or documented intraperitoneal penetration. In the case of a tangential GSW that appears to traverse only the soft tissues of the abdominal wall, diagnostic peritoneal lavage (DPL) or laparoscopy can be performed to confirm or exclude peritoneal penetration. If peritoneal penetration is identified, laparotomy should then be performed to permit thorough and systematic evaluation for intraabdominal injuries.

This conventional approach to the management of abdominal GSWs in stable trauma patients has been challenged recently by several studies from high-volume trauma centers.(4–8) Studies from these centers have demonstrated that asymptomatic, hemodynamically stable patients with abdominal GSWs may undergo selective nonoperative management (SNOM) without a significant increase in morbidity or mortality. In one large retrospective series of 1,856 patients with GSWs to the abdomen, 712 (38%) patients overall were successfully managed
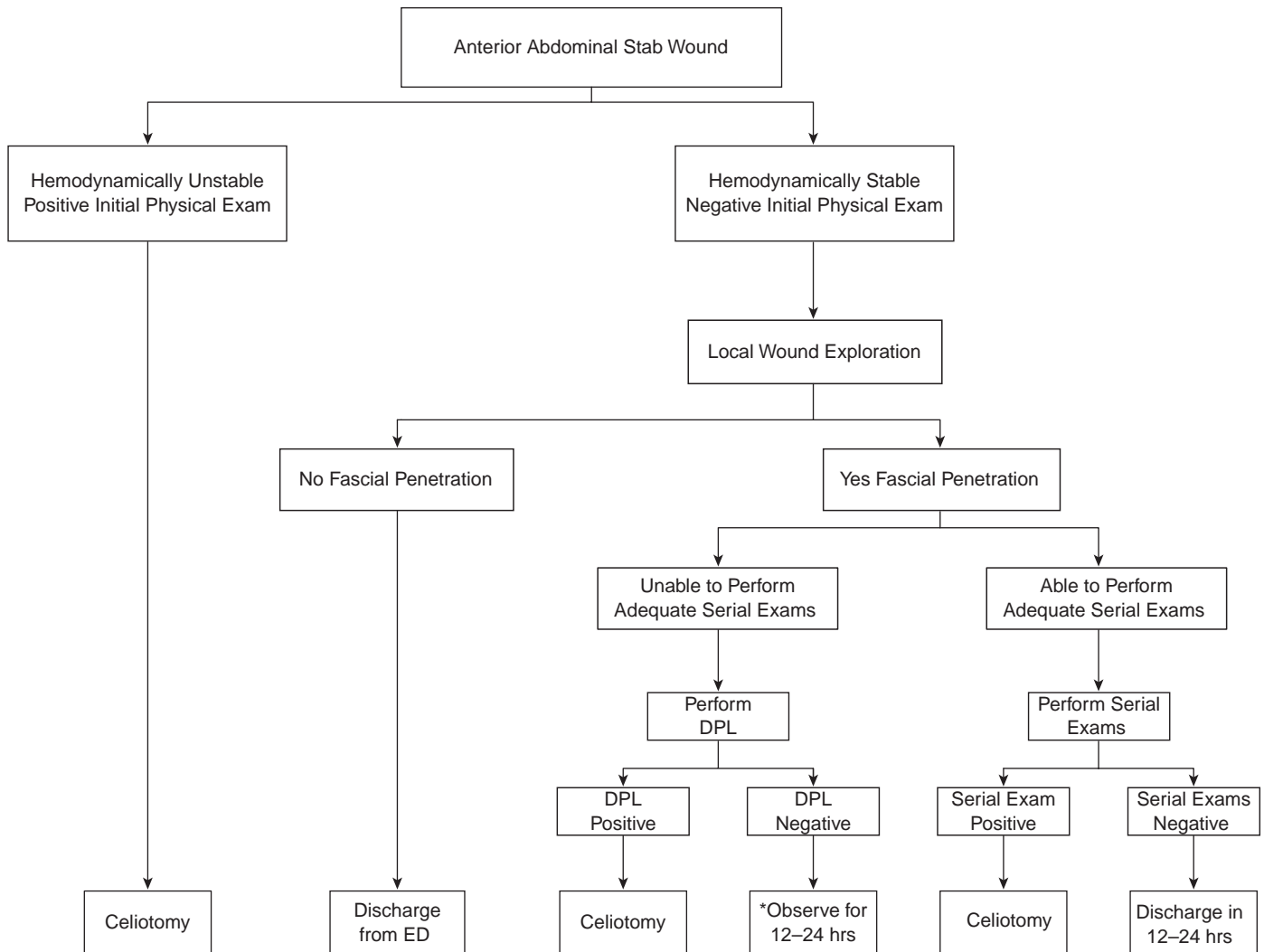
Figure 14.1 Diagnostic workup for anterior abdominal stab wounds.

without operation.(8) In that study, 10% of patients (80/792) originally selected for NOM required delayed operation. Five (6%) of these patients developed complications (four patients developed abscesses treated by CT guided drainage) giving an overall complication rate of 0.3% for the series. The number of delayed laparotomies was lower still in centers that used a more stringent management protocol. At the University of Miami, all patients meeting criteria for SNOM underwent CT scanning. (7) If peritoneal penetration was confirmed on CT, an exploratory laparotomy was performed. Equivocal CT findings were treated as if there was peritoneal penetration, and either cavitary endoscopy or laparotomy was then performed. Following this protocol, 53 of 83 (64%) patients meeting criteria for SNOM in that institution were found on CT scan to have no peritoneal penetration and avoided laparotomy. Fifteen (18%) patients had CT findings consistent with peritoneal penetration. Celiotomy was performed in eleven, while four patients had trajectories clearly limited to the right thoracoabdominal region and were successfully managed nonoperatively. An additional 15 patients (18%) had equivocal findings on CT scan. All but one of these patients underwent further study to confirm or

rule out the need for laparotomy. There were no missed injuries or delays in laparotomy among these 14 patients. In the 15th patient with equivocal CT findings, the attending surgeon chose not to proceed with diagnostic laparoscopy (DL) or exploratory laparotomy as per the protocol and that patient developed an acute abdomen from an ischemic colon 24 h after initial injury. Thus, in that series, when the management protocol was strictly followed, the overall accuracy of the protocol for determining the need for laparotomy was 100%.

At the time of this publication, SNOM for trauma patients with GSWs to the abdomen is not widely accepted throughout the United States. However, the data currently available support the concept that serial observation used in combination with CT scanning and other diagnostic testing can be safely used to reduce the rate on nontherapeutic laparotomies in a select subset of patients with GSWs to the abdomen. In these series, the subset of patients that were successfully managed nonoperatively had GSWs located in the flank and posterior abdomen or had trajectories limited to the thoracoabdominal region.(4, 6–8) In these patients, the organs most commonly injured were the liver and kidney. The most common organ injured in patients
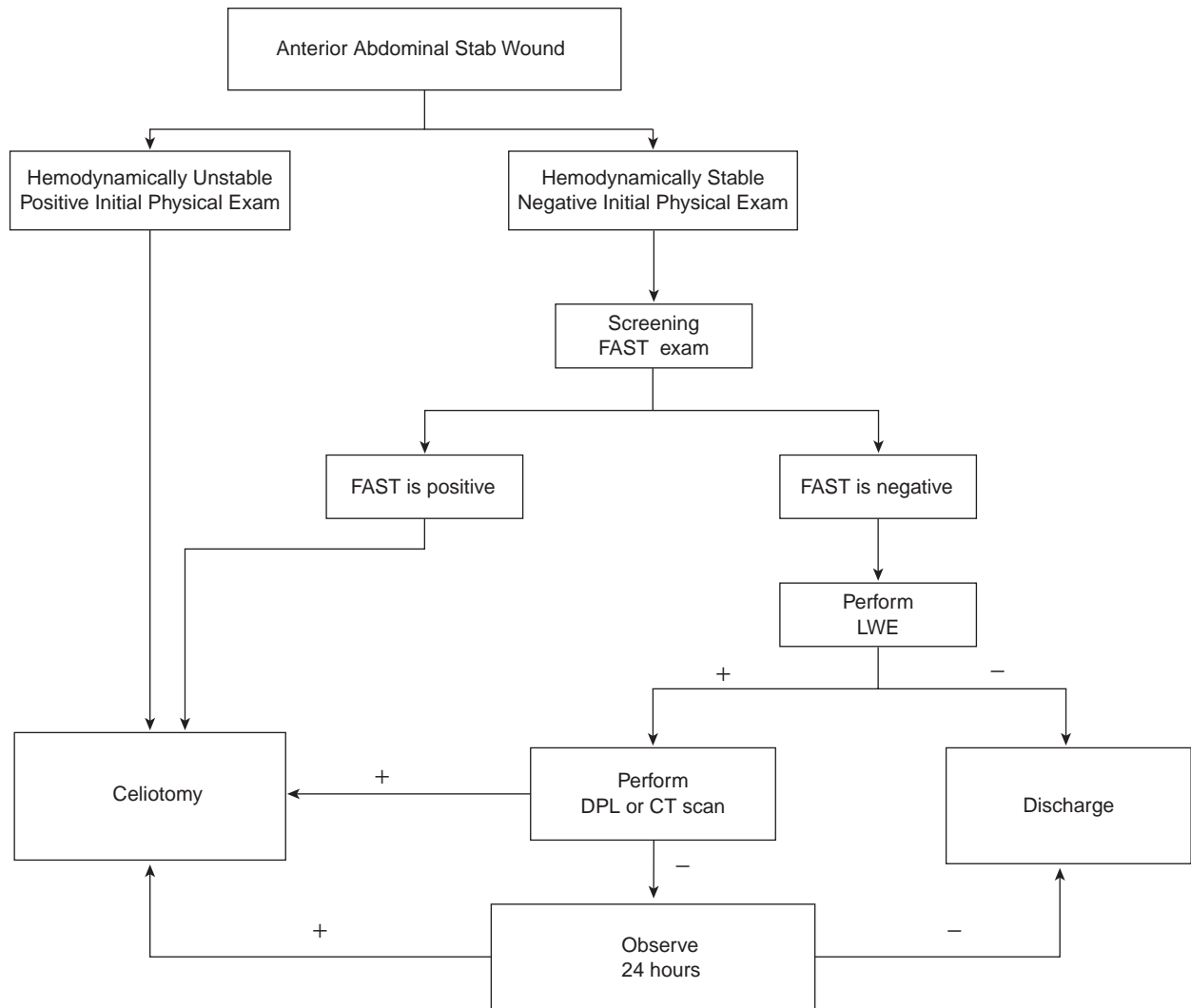
Figure 14.2 Alternative diagnostic workup for anterior abdominal stab wounds utilizing screening fast exam.

initially selected for NOM that went on to need laparotomy was the colon.(6–8) Thus, in general, patients with anterior abdominal GSWs not limited to the right upper quadrant will likely require laparotomy.

In contrast to patients with anterior abdominal GSWs, patients with stab wounds to the anterior abdomen who are hemodynamically stable have much lower incidences of intraabdominal injury, and only 75% of stab wounds actually penetrate the peritoneum.(9) Thus, a policy of mandatory exploration in all patients with abdominal stab wounds would result in a very high rate of nontherapeutic laparotomies which carry a complication rate of 8–41%.(10, 11) In addition, the average hospital length of stay for patients who undergo uncomplicated or complicated nontherapeutic laparotomies is 5.1 and 11.9 days, respectively.(11) Thus, a more selective approach in this patient population is warranted, and standard management algorithms for stable patients with penetrating abdominal stab wounds currently rely on the use of serial exams, diagnostic tests, or a combination of the two. Algorithms used by two different trauma centers in the

diagnostic workup for anterior abdominal stab wounds are shown in Figures 14.1 and 14.2.

DIAGNOSTIC MODALITIES IN HEMODYNAMICALLY STABLE PATIENTS WITH STAB WOUNDS TO THE ABDOMEN

Physical Exam with Serial Observation

Clinical observation with serial exam in stable patients with stab wounds to the abdomen was advocated as early as 1974.(12) Other studies in the 1980s supported this paradigm. For example, serial physical exams in a series of 651 patients with abdominal stab wounds carried a laparotomy rate of 53% and an observation rate of 47%. The negative laparotomy rate in this study was only 5% but, more importantly, only 2.9% of patients that underwent initial observation required subsequent surgery.(13) Thus, frequent physical reexamination is considered a safe and practical method of management for patients with penetrating abdominal injury providing the surgeon has the ability to assure serial examination. In situations when it is not feasible to perform frequent

serial examinations by senior surgical personnel, the workup for such patients should utilize other diagnostic modalities to avoid unnecessary delay in recognition of hollow viscus injury. Many trauma centers, including that of the authors, prefer to determine peritoneal penetration at the time of presentation—not only to avoid delay in diagnosis but also to allow the early discharge of patients with no peritoneal penetration.(14)

Local Wound Exploration

One of the critical questions in managing patients with penetrating abdominal trauma is whether the offending agent has entered the peritoneal cavity. In some patients, peritoneal violation is immediately obvious by the presence of omental or bowel evisceration through the wound. Although recently challenged (15), laparotomy is recommended in these patients because of (1) the likelihood of associated injuries, (2) an increased risk of infection with reduction of the exposed viscera, and (3) the need to repair the ventral wall defect to prevent future hernia. However, the majority of patients with stab wounds to the abdomen do not present with evisceration and thus, fascial penetration cannot be detected unless some diagnostic procedure is performed. One such commonly used procedure is local wound exploration. This technique can be performed in stable patients with a stab wound to the anterior abdomen, defined as the area bordered by the anterior axillary lines laterally, the nipple line superiorly, and the inguinal crease inferiorly. It should not be performed for stab wounds to the lower chest, flank, or back or in patients with significant obesity, multiple stab wounds, or any existing indication for laparotomy.

If the anterior fascia is found intact upon wound exploration, there is no risk of intraperitoneal injury, and the patient can be safely discharged from the emergency room provided there is no other indication for admission. On the other hand, fascial penetration is considered evidence of peritoneal violation and mandates further evaluation.

The efficacy of local wound exploration as the first diagnostic step in asymptomatic patients with anterior abdominal stab wounds has been well documented. In one prospective study, 26% of 572 patients were found on local wound exploration to have no fascial penetration.(16) No patient in that group required laparotomy either at presentation or during a 1-month follow-up period.

How Is Local Wound Exploration Performed?

Local wound exploration is best performed in the emergency department using strict sterile technique. After the region surrounding the wound is prepped and draped, the wound edges are infiltrated with local anesthesia. Once anesthetized, the wound edges are sharply extended to allow for retraction of the subcutaneous tissues and direct visualization of the anterior rectus fascia. Alternatively, the wound can be gently probed with a Q-tip or a metal probe taking care not to create a false tunnel, and the wound cut open on top of the probe until the end of the tract is identified. Additional diagnostic studies are warranted if fascial penetration cannot be confirmed. On the other hand, if the depth of the wound and the tract are visualized and there is no evidence

of fascial penetration, the wound should be well irrigated and closed primarily.

Diagnostic Peritoneal Lavage

The rationale for using diagnostic peritoneal lavage (DPL) is its ability to quickly determine the presence of intraperitoneal injuries requiring surgical intervention. This minimizes the number of nontherapeutic laparotomies without increasing morbidity and mortality related to potential delays in operative management. Since unstable patients with penetrating abdominal trauma go directly to the operating room, DPL is particularly useful in stable patients admitted to centers where initial FAST (focused abdominal sonography for trauma) (if done) was negative or, local wound exploration was positive, and frequent serial examinations are not feasible (see Figures 14.1 and 14.2).

DPL has an overall accuracy of 89–95% in identifying the need for surgical exploration.(16–18) Nevertheless, its accuracy is dependent on the criteria one chooses to constitute a "positive" lavage. Lower RBC count thresholds increase the sensitivity of the DPL and reduce the rate of missed injury. On the other hand, low counts also increase the incidence of nontherapeutic laparotomies. For example, DPL has a sensitivity of 59 and 100% when a count of 100,000 or 1,000 RBC/mm^3 is used, respectively.(16) However, using an RBC count of only 1,000 RBC/mm^3 results in an unnecessary laparotomy rate of 32%.(19) At the Kings County Hospital Center, we consider an RBC count of 20,000 cells/mm^3 as a positive indication for laparotomy in patients with penetrating abdominal stab wounds. In our experience, this threshold count has an accuracy of 95% and is associated with a very low rate of nontherapeutic laparotomies (unpublished data).

The only absolute contraindication to performing DPL is an existing indication for exploratory laparotomy such as hemodynamic instability, evisceration, or diffuse peritonitis. Relative contraindications include prior abdominal surgery, morbid obesity, coagulopathy, and known ascites in liver or kidney failure patients.

Of note, diaphragmatic defects created by penetrating mechanisms are small and rarely produce clinical or radiological abnormalities in the early post-injury period. Yet the morbidity due to delayed herniation of bowel is significant.(20) Thus, for stab wounds to the thoracoabdominal region where the risk of diaphragm injury is greatly increased, a lower threshold between 5,000 and 10,000 RBCs/mm^3 has been traditionally recommended. A cell count of 5,000/mm^3 has been shown to lower the false-negative rate to < 10% for isolated injury to the diaphragm.(21)

Other criteria for a positive DPL include a WBC count > 500 cells/mm^3, the presence of bacteria on gram's stain, or the finding of bile or particulate matter in the aspirate.(21–23)

How Is Diagnostic Peritoneal Lavage Performed?

The DPL can be performed using an open or closed technique. In the open technique, the skin is incised through an infraumbilical incision and the abdomen dissected down to the peritoneum. The peritoneum is then incised and the catheter inserted into the peritoneum under direct vision. One liter of warmed isotonic fluid (Ringer's lactate or normal saline) is then instilled into the

abdominal cavity and then recovered. The recovered fluid is then analyzed for red cell count, white cell count, bile, and particulate matter. The open technique should always be used in patients with prior abdominal surgery to reduce the risk of puncturing bowel that may be adherent to the anterior abdominal wall. The closed technique requires only a very small infraumbilical skin incision followed by a blind puncture of both the fascial layers and peritoneum. The DPL catheter is inserted blindly into the peritoneal cavity using a Seldinger technique. Despite initial concerns, the closed method for DPL has been shown to be as safe and effective as the open technique, and it is the diagnostic procedure of choice in our institution for stable patients with stab wounds to the anterior abdomen and no history of prior abdominal surgery.

Although by default DPL should be performed using an infraumbilical approach, there are several situations in which a supraumbilical route is preferred. These include complex pelvic fractures, where the catheter may puncture a large pelvic hematoma, previous lower abdominal operations, and pregnancy.

Diagnostic Laparoscopy

Diagnostic laparoscopy (DL) has been advocated by some trauma centers for the evaluation of asymptomatic or mildly symptomatic patients with penetrating abdominal trauma. The major benefit of DL is its ability to detect peritoneal penetration. Several studies, conducted in the early 1990s, laid the foundations to using this technique. For example, a review of 40 patients that underwent DL for penetrating thoracoabdominal wounds reported that the DL was negative in 20 patients, and therefore avoided laparotomy in 50% of patients.(24, 25) Of the 20 patients with peritoneal penetration, 10 underwent therapeutic laparotomy based on the DL findings, whereas the remaining 10 patients had nontherapeutic laparotomy performed after hemoperitoneum was identified at laparoscopy. A larger series of 182 patients (99 stab wounds, 66 GSWs, and 17 blunt trauma injuries) yielded similar results.(26) In that study, 49% of patients had no laparotomy as DL demonstrated a lack of peritoneal penetration, 31% underwent therapeutic laparotomy, and 19% had an unnecessary laparotomy. The average length of stay for patients with an unnecessary laparotomy was 4.6 days.

The above studies demonstrated that DL is most valuable in the workup of thoracoabdominal wounds for ruling out diaphragmatic injury. Although DL is very efficacious in determining the presence or absence of peritoneal penetration, its cost effectiveness is unclear considering the rate of unnecessary laparotomy and lengths of hospital stay. For this reason, these authors favor the use of DPL over DL to determine the need for surgical intervention for most patients with stab wounds to the abdomen. We reserved the use of DL (or alternatively video assisted thoroscopy) for cases where diaphragm injury is highly suspected and there is no other indication identified for surgical exploration.

Computerized Tomography

Over the years, with newer technology and better imaging capability, the use of CT in the workup of patients with penetrating torso injuries has been increasing and is considered by many to be an effective diagnostic tool in these patients. Historically,

the use of CT scanning in patients with anterior abdominal stab wounds has been limited due to its poor ability to detect hollow viscus injury. Thus, the role of CT in diagnosing penetrating torso trauma evolved for the evaluation of back and retroperitoneal injuries. Reports on the use of CT scan in patients with anterior stab wounds emerged in the 1980s. In 1985, an early study reported a sensitivity of only 14% with a false-negative rate as high as 86%.(27) Four years later, a review of 50 patients with stab wounds to the anterior abdomen, back and flank, indicated that double-contrast CT scanning was adequate in detecting peritoneal penetration. Nevertheless, it was unreliable in detecting bowel injury and did not reliably demonstrate diaphragmatic lacerations.(28) Thus, traditionally, CT did not offer any advantage over either serial exam or DPL in determining which patients with anterior abdominal stab wounds needed celiotomy.

In contrast to stab wounds to the anterior abdomen, stab wounds to the back have a very low incidence of bowel injury due to the density of the paraspinal muscles and the vertebral column.(29) Furthermore, back stab wounds are more likely to inflict injuries limited to the retroperitoneum, which are more difficult to diagnose clinically. However, the use of rectal contrast to fill the colon in combination with IV and oral contrast during CT scanning has significantly improved the ability to identify retroperitoneal colon injuries. This technique, termed triple-contrast CT or CT enema, is highly accurate with a sensitivity of 100% for evaluating the retroperitoneum in patients with stab wounds to the back and flank.(30)

Thus, as shown in Figure 14.3, triple-contrast CT scan alone is adequate in the diagnostic workup for asymptomatic, hemodynamically stable patients with isolated stab wounds to the back since intraperitoneal hollow viscus injury is unlikely. The back is defined as the anatomic area from the left posterior axillary line to the right posterior axillary line posteriorly and from the tips of the scapula superiorly to the iliac crests inferiorly. In contrast to stab wounds to the back however, stab wounds to the flank may have an intraperitoneal and/or retroperitoneal component depending on the length of the offending agent and the direction of wounding. Accordingly, in patients with stab wounds to the flank, the surgeon must first determine whether the patient has an intraperitoneal injury requiring laparotomy. In patients who cannot be followed by serial examinations, this is best done by DPL. Once DPL has ruled out an intraperitoneal injury, the patient's retroperitoneum can then be effectively evaluated by triple-contrast CT scan (see Figure 14.4). The flank is defined as the area between the anterior axillary line and the posterior axillary line and extends superiorly to the sixth intercostal space and inferiorly to the iliac crest on either side.

As the technology for CT imaging has improved in recent years, there has been a resurgence of interest in proposing its use to evaluating all patients with penetrating abdominal trauma. A number of studies suggest that CT is useful in detecting peritoneal and retroperitoneal violation and in delineating the trajectory of the stab wound or missiles.(28, 30–32) For example, a 2004 study of the efficacy of triple-contrast CT in identifying peritoneal violation in patients with penetrating torso trauma demonstrated 97% sensitivity, 98% specificity, and 98% accuracy.(31) However, as only 55% of patients in that study sustained stab wounds and, as the study
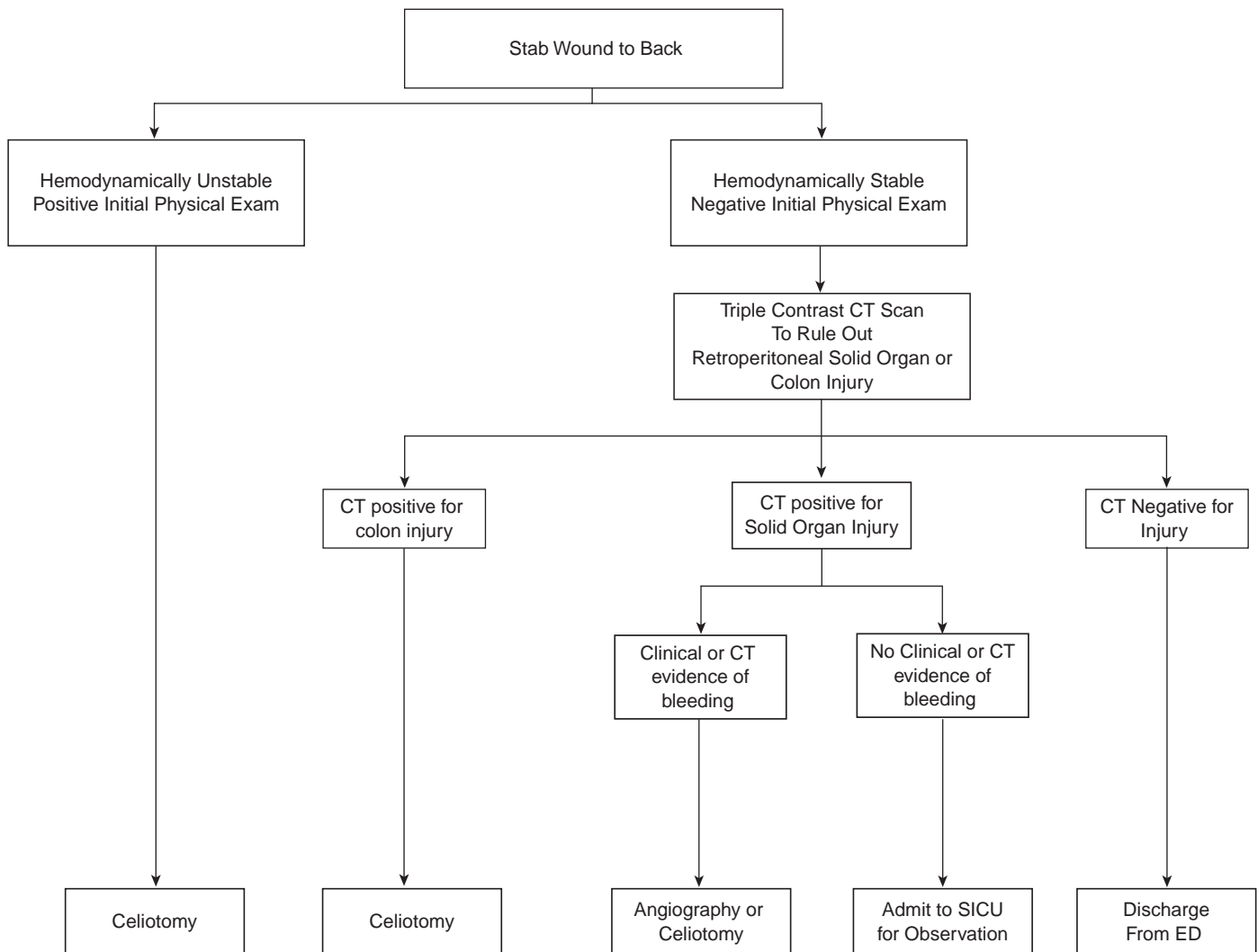
Figure 14.3 Diagnostic workup for stab wounds to the back.

included many patients with both injuries to the flank and back, its applicability to patients with anterior abdominal stab wounds is questionable. It should also be noted that the rate of nontherapeutic laparotomy in that investigation was 13% and that two patients failed to improve while being observed after CT scanning and subsequently underwent therapeutic laparotomy. More recently, a study of 67 patients with stab wounds to the anterior abdomen who underwent CT scanning reported an identifiable stab wound tract in 70% of patients.(33) However, despite the ability to identify the tract of the knife, actual peritoneal penetration could not be clearly determined in the majority of cases.

Thus, despite improved technology, CT scan continues to provide no diagnostic advantage over DPL or serial physical exam in determining which hemodynamically stable patient with an anterior abdominal stab wound needs to go to surgery. Used as an adjunct, it can provide useful information regarding the wound tract, the presence of solid organ injury, and the presence of retroperitoneal colon injuries for those patients with stab wounds to

the back and flank. A negative CT scan in a patient with an anterior stab wound to the abdomen does not rule out hollow viscus injury and thus would necessitate a period of serial observation and examination.

Ultrasonography
The role of ultrasonography (US) in the assessment of blunt abdominal trauma patients has been well defined and continues to expand. However, its usefulness for determining the need for operative intervention in the patient with penetrating injury is very limited. The earliest study in this latter group of patients, which reported a 14% false-negative rate and a 4% false-positive rate, concluded that the use of US in patients with penetrating injury is limited to those patients with multi-cavitary injuries or suspected pericardial injury.(34) In these cases, the US helped the surgeon rapidly identify which of the body cavities had the significant injury. Subsequent studies by several other investigators confirmed these results and conclusions. Three independent
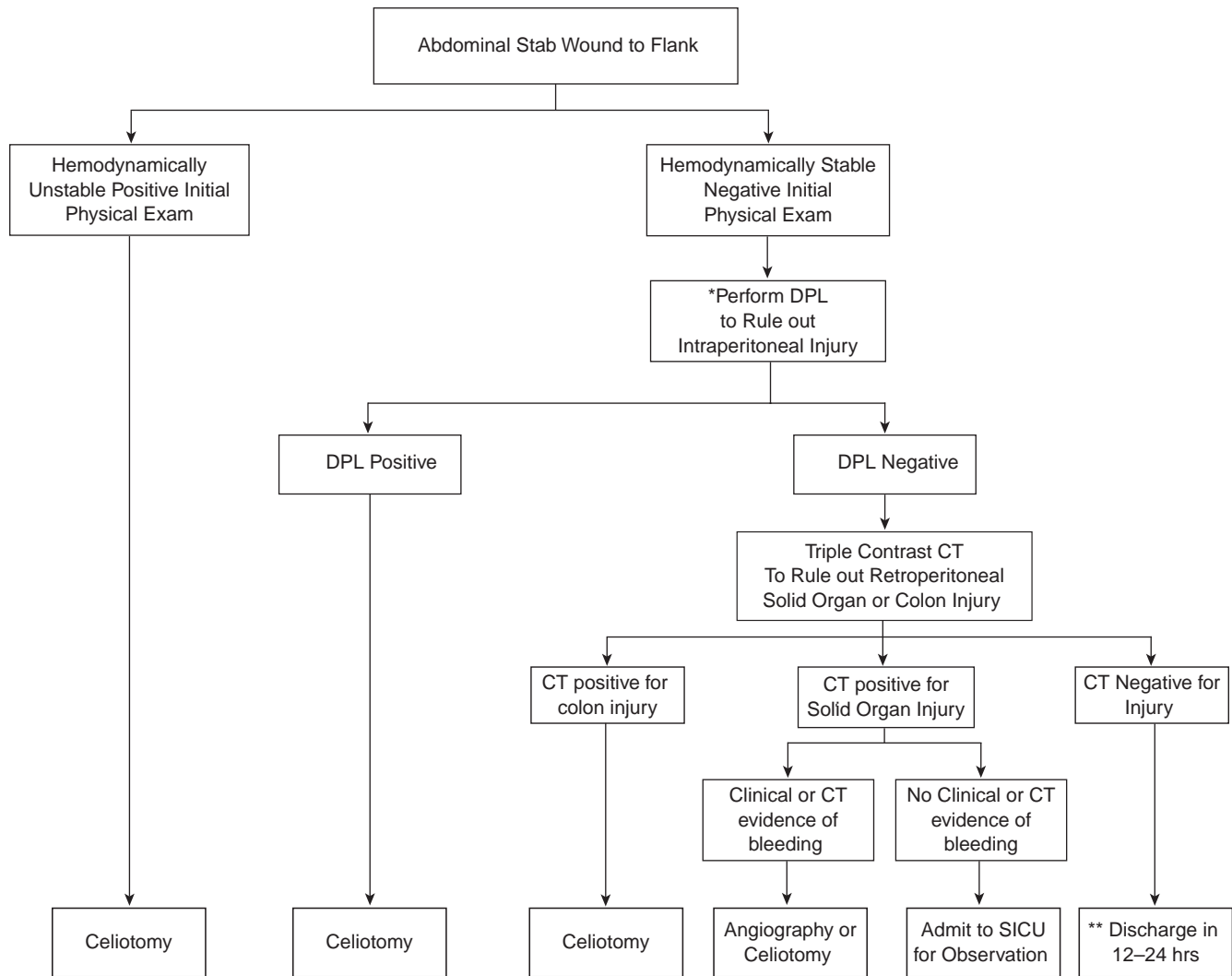
Figure 14.4 Diagnostic workup for abdominal flank wounds.

prospective series using US as the first diagnostic modality in patients with penetrating torso injuries demonstrated 9, 29, and 16% false-negative rates for predicting intraabdominal injuries needing surgery.(35–37) In each of these series, patients with negative ultrasounds were further evaluated with local wound exploration, DPL, CT, serial observation, or combinations of these studies. In one series, 50–60% of all hollow viscus injuries were missed.(36) In that study, 90% of 25 patients had positive physical findings that would have predicted the need for surgical intervention. These authors suggested that clinical judgment was equal or superior to ultrasound findings in patients with penetrating torso injury.

Thus, ultrasound may be useful as a rapid screening tool to quickly identify the presence of a large amount of free fluid in patients with penetrating abdominal injury. A positive test should prompt laparotomy, whereas a negative study should mandate additional studies or serial observation to definitively rule out serious injury. Ultrasound lacks the sensitivity to be used alone in determining the need for operative intervention in this patient population.

In the case patient, a local wound exploration confirmed fascial penetration of the stab wound. This finding together with the patient's increasing abdominal pain and localized peritoneal signs prompted the surgeons to take the patient directly to the operating room. DPL could have been an alternative approach, especially if the history and physical exam had not been clear. Further observation with serial examinations would not have been a good option in this case since the patient presented 4 h post-injury. Further observation would have likely delayed surgery with increased risk for intraperitoneal fecal contamination and concomitant morbidity.

OPERATIVE MANAGEMENT
There are several options for the operative management of colon injuries. These include (1) primary suture repair, (2) resection with primary reanastomosis, (3) colostomy, (4) repair

with proximal diverting colostomy, and (5) resection with externalization of the anastomosis through the abdominal wall. The latter is more of historical interest than of practical use and will not be discussed.

When managing colonic injury, it is important to note that the recommendations for definitive management have undergone significant evolution in the past several decades such that, at present, it is accepted that very few patients would not qualify for primary repair or anastomosis.

Prior to World War II, the mortality among individuals sustaining penetrating colonic injury was extremely high. To improve mortality, management guidelines for colonic injury were published in 1943 by the U.S. Surgeon General, which mandated exteriorization or proximal diversion in all soldiers with colonic injuries.(38) These guidelines were credited with improving survival toward the end of the war and were carried over into civilian practice, where they continued to be applied unchallenged for decades. However, as civilian injuries do not necessarily equate with war injuries, and with the development of efficient trauma systems and advanced trauma care, the practice of mandatory colostomy for colon injuries began to be questioned in civilian practices in the late 1970s. Routine colostomy for all patients with colonic injury was gradually replaced by primary repair in selected cases in the late 1970s, by liberal primary repair in most cases in the 1990s, and by 2001, the data supported that all colon injuries, including those requiring resection, should be managed by primary repair or anastomosis.

The concept of mandatory colostomy in patients with colon injury was first tested in a randomized prospective fashion in 1979 in a well-designed study which demonstrated that primary colon repair in a selective patient population was associated with fewer complications than colostomy.(39) As mortality rates from colon injuries continued to improve with time, other studies began to challenge the remaining contraindications for primary repair. These investigations demonstrated two important observations: (1) the method of colon management did not directly influence mortality or the incidence of colon-related abdominal complications and (2) primary repair can be performed with excellent results.(40–44) In those studies where primary repair had been compared to colostomy, wound infection and intraabdominal abscess formation rates were consistently higher in the colostomy group.(42, 44–47) Furthermore, a prospective study of 100 GSWs to the colon, conducted in an institution in which colostomies were routinely performed for all colon injuries requiring resection, reported much higher incidences (37.5%) of abdominal septic complications when compared to these other studies.(48)

Despite these data, many surgeons held steadfast in their unwillingness to perform colon resection with reanastomosis in patients with destructive colon injuries, fearing a potential anastomotic leak. Two recent studies finally addressed these beliefs.(45, 49) A prospective randomized multicenter trial was conducted by the American Association for Surgery on Trauma specifically to evaluate the role of diversion versus primary anastomosis in high-risk patients with penetrating colon injuries requiring resection.(49) In that study of 297 patients, 197 patients (66.3%) were managed by primary anastomosis and

100 (33.7%) were diverted by colostomy. The overall colon-related mortality was 1.3% (four deaths in the diversion group, no deaths in the anastomosis group). Colon-related abdominal complications occurred in 24% of all patients (primary repair 22%; diversion 24%). There were a total of 14 colon leaks postoperatively. Thirteen of the leaks occurred in the primary repair group (6.6%) and one occurred in a Hartmann's pouch. Of the 13 patients with colon leaks in the primary repair group, 9 occurred in colo-colonic anastomoses and 4 in ileo-colonic anastomoses, 2 had hypotension, 3 had transfusion of > 6 units of blood in the first 24 h, 9 had Penetrating Abdominal Trauma Index (PATI) scores > 25, 9 had Injury Severity Scores (ISS) > 20, and 2 had severe fecal contamination. However, on multivariate analysis, there were only three independent risk factors identified for the development of abdominal complications: severe fecal contamination, transfusion of > four 4 units of blood in 24 h, and single-agent antibiotic therapy. When these risk factors were controlled for, the surgical method of colon management did not affect the incidence of abdominal complications. Similar findings were shown by a retrospective series of 104 patients with destructive colon injuries.(50) In addition, this latter study also demonstrated that bowel resection and primary reanastomosis was a safe alternative when performed in conjunction with the need for damage control laparotomy (DCL), multiple reoperations, and the use of open abdomen or temporary abdominal closure techniques.

Thus, the method of colon management does not influence the incidence of colon-related abdominal complications irrespective of the presence or absence of any risk factors. Colonic diversion does not reduce the postoperative complication rate, and in fact, complication rates are often higher compared with a primary repair. In view of the worse quality of life and the need for an additional operation for closure with colostomy, current recommendations suggest that all colon injuries be managed by primary repair (suture repair or resection and reanastomosis) regardless of the patient's associated risk factors. The final decision to perform primary repair or diversion should be based on patient hemodynamic stability and the condition of the bowel at the time of surgery or reexploration.

In the case patient, a primary repair of the 3 cm descending colon injury was performed. In contrast to gunshot or shotgun wounds, most stab wounds are clean lacerations without associated surrounding tissue destruction, and thus, do not require debridement of the colonic wound and surrounding tissue. The need for additional debridement and the greater degree of tissue damage induced by GSWs make colonic resection more likely in this type of traumatic mechanism. However, regardless of the mechanism of injury, the need for resection, or the degree of fecal spillage, current studies support primary reanastomosis as the procedure of choice for colonic injuries. One exception to this notion would be the presence of significant hemodynamic instability requiring damage control, in which bowel exclusion is indicated until reoperation (see below).

DEATH AFTER COLON INJURY

The most common cause of death in patients with colonic injury is massive acute hemorrhage from associated injuries. This is followed by sepsis and multiple organ failure (51), which develop in < 5% of patients.(52) Like death from hemorrhage, the development of sepsis and multiple organ failure in these patients is usually related to associated injuries and events such as multiple transfusions, rather than the colon injury itself.

DAMAGE CONTROL SURGERY
FOR COLONIC INJURIES

As stated above, isolated colon injuries are not associated with massive hemorrhage or significant physiologic alterations to warrant damage control procedures. However, colon injuries are frequently associated with other conditions that do require a damage control approach. In such cases, the main management goal is to control fecal spillage and remove any non-viable tissue. If the injury to the colon is limited to one or two holes without significant tissue destruction, a rapid repair by either a handsewn, single layer, whipstitch or a noncutting stapling device should be performed. In the case of GSWs, care must be taken to repair the injury using healthy tissue beyond the zone of blast injury. All repairs must be carefully inspected at the time of reoperation. Frequently, only reinforcement of the handsewn closures with a second layer of seromuscular sutures is required. In situations where there are multiple holes in close proximity, significant tissue destruction, or vascular compromise to the colon, it is best to resect these segments with a cutting stapling device without performing a colostomy, ileostomy, or any definitive treatment. Definitive treatment should be executed at reexploration.

The definitive management of colonic injuries on reexploration should be based on the patient's stability and the condition of the bowel. Normal appearing bowel in the hemodynamically stable patient warrants primary anastomosis. The presence of mild to moderate bowel edema or the inability to perform primary fascial closure (open abdomen) should not deter the surgeon from pursuing this recommendation. Indeed, a study of seven colonic anastomosis for destructive colon injuries after DCL reported only one anastomotic breakdown.(53) Furthermore, a recent review of 29 patients with destructive bowel injuries who required vacuum pack closure of the abdomen demonstrated that bowel resection and primary anastomosis can be performed safely in these settings.(50)

INFECTIOUS COMPLICATIONS

Overview

Both local and remote infectious complications may develop after colonic injury. The most common local complication is an intraabdominal abscess, which has been reported to occur in 5–15% of patients.(21, 52) Suture-line failure and fecal fistula may also occur following colon injuries with a reported incidence of up to 2% in patients undergoing primary repair.(52) Although fecal fistulae most commonly occur after primary repair, they can also result from a missed colonic injury or from the suture line of the Hartmann's pouch when an end colostomy is performed.

A superficial wound infection is another common local complication in patients after colonic injury. However, this complication can be completely avoided by leaving the skin and subcutaneous tissues open.(2, 3) Although one study in which over 50% of 727 patients with colon injuries had primary skin closure demonstrated no inordinate incidence of wound infection (51), we have been unable to duplicate these results. In our institution, we have had unacceptable rates of wound infection leading to high rates of fasciitis and wound dehiscence when attempts at primary closure were performed in patients with hollow viscus injury. This necessitated a mandatory practice of leaving skin wounds open for either delayed primary closure or healing by secondary intention (unpublished data). If one chooses to close skin wounds primarily after colon injury, it is advised to limit this practice to patients with minimal contamination, little subcutaneous tissue, no associated injuries, and no prolonged shock.(52)

One underestimated complication in patients with colon injury is infections within missile or stab wound tracts.(2, 54) One study of 151 patients with GSWs to the colon demonstrated a 26% septic complication rate in patients with retained bullets compared to only 16% in those without retained bullets.(54) The higher rate in those with retained bullets was due to abscesses developing around the retained missile. In that study, it was noted that 79% of patients with missile or missile track abscesses developed their abscess within the psoas muscle and that both CT guided and operative drainage tended to fail if the foreign body was not removed at or before drainage. Thus, a reasonable attempt at bullet extraction should be made at the time of surgery for those bullets that have traversed the colon and become lodged in muscle and soft tissues.

Patients with penetrating colonic injuries can also develop infectious complications secondary to a newly constructed colostomy. These include stomal necrosis and peristomal abscesses. In one retrospective series of 311 patients with penetrating colonic injuries, 78 (25%) of patients developed infections.(47) On multivariate analysis, only two factors were found to be independent risk factors for infectious complications: presence of an ostomy and a PATI score > 30. Thus, the creation of an ostomy in high-risk patients does not protect them from infectious complications and may, in fact, independently contribute to local abdominal infections.

Management

Most septic complications after colonic injury can be managed nonoperatively. Intraabdominal abscesses can usually be treated with percutaneous drainage guided by either CT scan or ultrasound. Occasionally a fecal fistula will be noted during or after the drainage of an abscess. Such fistulas can also be managed nonoperatively provided the patient has no systemic sepsis, and the fistula is adequately controlled by the drainage catheter. Follow-up fistulograms or CT scanning may be required to confirm the resolution of these processes. At that point, the drainage catheter can be removed.

Patients who develop fecal fistulas that drain through their abdominal incision are more often septic. If the patient presents with peritonitis, particularly within the first few days after surgery, operative intervention is recommended. Operative management

includes resection of the fistula with either primary reanastomosis or creation of a colostomy, depending on the patient's physiologic status, and drainage of intraabdominal collections or abscesses. In such patients, the surgical wound should also be examined closely for evidence of necrotizing fasciitis, which would require immediate debridement. In the absence of diffuse peritonitis or fasciitis, an emergent CT scan can be done to search for intraabdominal abscesses and to rule out leakage of fecal content into the peritoneal cavity. Localized intraabdominal abscesses in the absence of fecal spillage can be treated as a controlled fistula and managed nonoperatively, as outlined above.

> Patients who sustain colon injury are at increased risk for development of intraabdominal abscesses postoperatively. An intraabdominal abscess was suspected in our case patient when she became febrile and developed an elevated WBC count on POD 6. The abscess was confirmed by CT scan, and since she was otherwise stable with no generalized peritonitis, the decision was made to drain the abscess percutaneouly using CT guidance. Care was also taken to rule out other sources of infection such as a knife tract or a superficial wound infection since her laparotomy wound was closed in a delayed primary closure. The drainage procedure yielded purulent fluid consistent with a simple abscess. The presence of feculent material would have prompted a fistulogram to rule out breakdown of the colonic repair.

Antibiotic Treatment

Abdominal and soft tissue infections after penetrating colonic injury arise from the patient's indigenous bacterial flora and are enhanced by the risk factors described above. Appropriate antibiotic administration reduces but does not completely eliminate these infections. Even under optimal circumstances, 7–36% of patients will still develop infectious complications.(2, 55–57)

Since in penetrating colonic trauma contamination already exists on admission to the hospital, antibiotic administration cannot be defined as prophylaxis but rather as early empiric therapy to prevent infection. Nevertheless, the role of antibiotics in reducing wound and intraabdominal infection rates in colorectal surgery was established by studies of prophylactic treatment in elective procedures. For example, a landmark study published in 1969 reported that antibiotic prophylaxis dramatically reduced infection rates from 30% in a placebo group to 7.4%.(58)

The timing of antibiotic administration is also extremely important in determining infectious outcomes after penetrating injury. Both animal (59, 60) and human studies (61) confirmed that the sooner antibiotics are administered to the time of contamination the more effective they are. An infection rate of 7% has been demonstrated in a study of 295 patients with penetrating abdominal trauma who received preventative antibiotics preoperatively. In contrast, infection rates in those patients who received their antibiotics intra- or postoperatively were 33 and 30%, respectively.(61) Antibiotics administered beyond 3 h from injury have little therapeutic effect.(59–61)

Which Antibiotic Should Be Administered?

As with all clinical situations, the choice of antibiotic in penetrating colon injury should be based on the drug's efficacy, safety, and cost. Given equal efficacy, the least toxic and the lowest priced antibiotic should be used. Efficacy is determined by the sensitivity of the colonizing bacteria to the chosen antibiotic.

Staphylococcal wound infections are relatively uncommon after penetrating colon injury and when they occur they are usually the result of a break in technique. The vast majority of bacteria responsible for the infectious complications after colonic injury come from the patient's own intestinal flora. Bacterial colonization increases with progression through the intestines. The small intestine has colony counts of approximately 10^4 organisms/ml of gram-positive and aerobic, gram-negative bacteria. Counts increase to 10^7 organisms/ml in the distal ileum with increasing numbers and varieties of anaerobes.(62) Bacteria are present in the large bowel in much higher concentrations that can reach 10^{12} organisms/ml. Colonic bacteria are predominantly anaerobic organisms mixed with gram-negative aerobes of the Enterobacteriacea group; 90% of colonic flora are anaerobic organisms. Therefore, it is not surprising that colonic injuries are associated with a 10–15 % infection rate compared to a 5% rate in small bowel trauma.

To effectively prevent infection after colonic wounding, it is critical to select antibiotics that cover colonic flora. Regimens that lack anaerobic coverage have twice as many infections as regimens that cover both Enterobacteriaceae and anaerobes.(63) Since the surgeon cannot predict preoperatively which organs will be injured and, as early antibiotic administration is essential to preventing postoperative infection, all patients with penetrating abdominal injury should be presumed to have colonic injury and be treated for it preoperatively. Antibiotics coverage should be modified postoperatively based on the injuries identified at the time of surgery.

The most cost-effective regimen would include a safe single agent directed against gram-positive and gram-negative aerobes as well as anaerobic organisms. A second- or third-generation cephalosporin or an expanded penicillin is most commonly used. Double-agent regimens, which combine an anti-anaerobic drug (clindamycin or metronidazole) with an aminoglycoside (or aztreonam) are useful in patients with penicillin allergies. More recent studies have shown that single-agent beta-lactam antibiotics are also effective.(2, 64)

How Long Antibiotics Should Be Administered?

Until recently, the duration of antibiotic treatment in patients with colon and other hollow viscus injury was controversial and the subject of much debate. Over the past 20 years, the traditional 1-week antibiotic course was challenged and several clinical studies reported similar postoperative infection rates in patients receiving long or short (12 h to several days) courses of antibiotics.(55, 56, 65–72) Nevertheless, many surgeons argued against these reports and continued to resist this shift in practice.

This debate was finally put to rest in 2000 by a prospective, randomized, double-blind, placebo-controlled trial comparing a 24 h versus a 5 day-course of antibiotic treatment in 317 patients

with penetrating abdominal trauma and at least one hollow viscus injury.(2) This study, which included 162 patients (51%) with one or more colon injuries, reported a 10% surgical site infection rate in those receiving the 5-day course and an 8% rate in patients receiving only 1 day of antibiotics Eleven percent of patients given 5 days of treatment experienced nonsurgical site infections compared with 20% of those patients treated for 24 h only. However, this difference was not statistically significant. Colon injury was not identified as an independent risk factor for either surgical or nonsurgical site infection in that study. Only the total number of blood units transfused and a PATI score ≥ 25 were found to be independently associated with the development of postoperative infections. Thus, this well-designed study demonstrated that there is no added benefit to treating high-risk patients with penetrating colon and/or other hollow viscus injury with antibiotics beyond 24 h.

> Although the choice and the duration of antibiotic therapy in our index patient were appropriate and consistent with the standard of care, the patient did not receive her first dose of antibiotic until 4 h after injury due to her delay in presentation. This delay in antibiotic administration added to her risk for postoperative infection since antibiotics administered beyond 3 h of contamination have little therapeutic effect (see above).

Intraperitoneal Washout

The main objective in the surgical management of intraperitoneal hollow viscus injuries is to eliminate the source of ongoing bacterial contamination and to prevent local and systemic infection. The intent of peritoneal lavage is to decrease the bacterial load within the peritoneum in order to facilitate bacterial clearance by normal defense mechanisms. Intraperitoneal washout has long been taught as an essential step in contaminated procedures to reduce infectious complications postoperatively. The act of abdominal washout is almost as old as abdominal surgery itself and yet, surprisingly there is little evidence-based data to document its efficacy.

The concept of intraoperative peritoneal lavage (IOPL) is attributed by many to Dr. Joseph Price, who in 1905 first wrote of its beneficial effects in patients with peritonitis.(73) Others attribute the concept to Dr. Torek who in 1911 reduced the mortality rate of generalized peritonitis from 100 to 33% by generous lavage with "gallons of normal saline."(74) Subsequently, IOPL with copious amounts of fluid became a tenet in the surgical management of patients with intraperitoneal contamination and peritonitis.

However, this technique did not escape controversy and critics. In 1910, IOPL fell into disrepute after Deaver proposed that the act of abdominal irrigation would lead to worse outcomes by converting a localized infection into a generalized one.(75) Despite the lack of strong data, fear that intraabdominal irrigation would disseminate contamination grew and resistance to IOPL by many surgeons continued for decades.(76, 77) It wasn't until 1957, when Burnett produced both experimental and clinical data supporting irrigation of a

contaminated peritoneal cavity, that the practice of IOPL regained popularity.(78) In 1972 the theory that IOPL would worsen outcome by disseminating intraperitoneal contamination was disputed by a well-designed animal study, which demonstrated no difference in mortality between animals subjected to disseminated or localized intraperitoneal contamination.(79) In this study of 35 dogs, the mortality was 59% in the diffuse contamination group and 61% in the localized contamination group. The cause of death in both experimental arms was acute generalized peritoneal sepsis diagnosed at necropsy. All surviving dogs were sacrificed at 1 month, and there were no intraperitoneal abscesses noted in the survivors from either group. Furthermore, follow-up peritoneal cultures were negative among all dogs that survived the infectious challenge, further disputing the theory that dissemination of contaminates by peritoneal irrigation leads to worse outcomes.

To this day, however, the role of IOPL continues to be controversial and there is ample experimental and clinical literature, which supports (80–88) or disputes (74, 88–93) the effectiveness of peritoneal lavage. This debate continues to bubble, as many of the studies investigating this issue are plagued with design flaws including the lack of control groups (80–83), inadequate antibiotic coverage (80, 81, 85, 91), and small population size.(94) In addition, most clinical studies designed to evaluate the role of IOPL are composed of patients presenting in an advanced state of peritonitis, when systemic inflammation is already primed.(92, 94)

Other yet unresolved controversies regarding IOPL include the addition of antibiotics to the irrigation solution and the optimal volume of irrigation fluid that should be used.

Although many studies were conducted to evaluate the effectiveness of antibiotic- or antiseptic-containing solutions, they failed to provide a definitive conclusion due to their retrospective nature or faulty design.(74) At present, there is only one well-designed study that has shown a significant survival advantage using antimicrobial lavage in an animal model of established peritonitis.(94)

Similarly, there is little data to support a specific volume or choice of irrigation fluid during IOPL. Although the volume and choice of irrigation solution varied significantly in the studies cited above, most reports support irrigation with 8–10 l and the use of an isotonic solution. Interestingly, one nonrandomized, retrospective study suggested that even much larger volumes (≥ 30 l) of irrigation are needed to improve outcomes in patients with generalized peritonitis.(95)

Thus, there is no reliable data to support or dispute the use of IOPL in patients with peritoneal contamination, and the frequency of its use along with the volume and the choice of lavage fluid vary widely among surgeons. A recent survey conducted among 118 surgeons in Britain showed that 97% perform IOPL.(96) The majority of these surgeons lavage until the fluid is clear; 20% lavage with more than 1 l, and 17% use between 0.5 and 1 l. In the case of gross contamination with pus or fecal peritonitis, 47% use saline as the lavage fluid, 38% aqueous betadine, 9% water, and 3% use an antibiotic-containing lavage.

In spite of the lack of data in support of performing IOPL and since some studies clearly demonstrated no untoward effects following this procedure, most surgeons consider fecal contamination and

Table 14.1 Evidence Based Recommendations for the Diagnostic Workup for Patients with Penetrating Abdominal Wounds and Determining the Need for Celiotomy.

Diagnostic Workup For Penetrating Wounds To The Torsos	Evidence level	References
Asymptomatic, hemodynamically stable patients with stab wounds to the anterior abdomen require a selective approach to celiotomy.	I (A)	4, 11
Serial observation and reexamination is a safe and reliable method to determine the need for celiotomy in hemodynamically stable, asymptomatic patients with penetrating abdominal wounds.	I (A)	7, 8
Diagnostic Peritoneal Lavage is a sensitive screening test to identify intraperitoneal injuries that require celiotomy.	I (A)	11, 12, 13
Laparoscopy is not a reliable screening test to determine the need for celiotomy.	I (A)	19, 20, 21
Laparoscopy has a high sensitivity for diagnosing diaphragm injury in patients at high risk from thoracoabdominal wounds when there is no other indication for celiotomy.	I (A)	19, 20, 21
Ultrasonography is unreliable in predicting intraperitoneal injury in patients with penetrating trauma and should not be used as a screening test to determine the need for celiotomy.	I (A)	29, 30, 31, 32
Triple contrast CT scan will reliably identify solid organ and retroperitoneal colon injuries.	I (A)	25
CT scan does not reliably indentify intraperitoneal hollow viscus injury and if used without DPL patients with anterior abdominal wounds will require continued serial observation and examination.	I (A)	23

Table 14.2 Evidence Based Recommendations for the Operative Management of Colon Injury.

Operative maangment of colon injury	Evidence level	References
Primary repair with bowel resection and reanastomosis does not increase the risk of postoperative morbidity and is the recommended method of management for essentially all colon injuries.	I (A)	40, 44
Primary repair with bowel resection and reanastomosis can safely be performed after damage control surgery and in patients managed with open abdomen techniques.	I (C)	45, 48
Minimizing infectious complications after colon injury		
An antibiotic that covers colonic flora should be initiated as soon as possible after abdominal wounding.	I (B)	54, 55, 56, 57
Twenty four hours of antibiotic treatment is adequate in patients with colon injury. There is no added benefit to longer courses of antibiotic therapy.	I (A)	2
Intraoperative peritoneal lavage in patients with fecal contamination from colon perforation does not increase postoperative morbidity or infectious complications.	II (B)	74
It is suggested that intraoperative peritoneal lavage be performed after colon injury until all blood and visible contamination is removed in patients after colon injury.	II (C)	91

the presence of blood in combination with feces a major harbinger of postoperative infection and will perform IOPL. No solid recommendation can be made as to the required amount of the irrigation solution although it is generally agreed that the peritoneal cavity should be irrigated at least until all visible signs of blood and debris are removed.

> In our index case, IOPL was performed with 8 l of normal saline at the completion of the operation. Traditional surgical teaching has been to perform copious IOPL in patients with intraperitoneal contamination although there is no evidence-based literature to support this practice. The patient developed an intraabdominal abscess despite the copious lavage, which is not uncommon in this patient population.

LEVEL OF EVIDENCE

Evidence-based recommendations for the diagnostic workup and management of patients with penetrating abdominal wounds are presented in Table 14.1 and 14.2.

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15   Rectal injury with pelvic fracture
Kimberly K Nagy

A 72-year-old male restrained driver presents to the emergency room of the trauma center after hitting a tree at 40 mph. His primary survey is intact. His secondary survey reveals tenderness over the symphysis pubis and bright red blood per rectum.

OPEN PELVIC FRACTURES

What is the epidemiology of rectal injuries associated with pelvic fractures?

Pelvic fractures occur in approximately 5% of all trauma patients. (1) Most are considered "closed," although approximately 5% are "open". An open pelvic fracture is associated with soft tissue or mucosal injury in continuity with the fracture. Rectal injuries are unusual following blunt trauma because the rectum is in a fairly protected position deep in the pelvis.(2) Rectal injuries occur in approximately 2% of closed pelvic fractures, but 23% of open fractures.(1, 3) The most common fracture pattern is pubic symphysis widening along with sacroiliac joint fracture or widening, in other words, resulting from an anterior–posterior compression mechanism.(1) In a small series by Brunner (2), all patients with a blunt rectal injury had an associated pelvic fracture.

What other injuries are associated with open pelvic fractures?

Is it not uncommon to have associated injuries when confronted with a pelvic fracture due to the proximity of genitourinary, gastrointestinal, and vascular structures.(4) In fact, 15–20% of pelvic fractures have significant intra-abdominal injuries. Due to the significant force required to cause a pelvic fracture, injuries to solid abdominal organs, thoracic structures, the brain, and other long bones are common.(2, 3)

Injuries to the genitourinary tract are seen in up to 7% of all pelvic fractures and should be considered.(1) Again, in Brunner's series, all patients had both a rectal injury as well as an injury to the bladder, urethra, or both.(2)

What diagnostic tests are indicated following an open pelvic fracture?

In addition to radiographic imaging of the bony pelvis, a search for associated injuries should be performed. Computed tomography (CT) or ultrasound (US) of the abdomen is indicated to rule out associated intraperitoneal injuries.(5)

Rectal injury is usually diagnosed during the secondary survey by visualization of blood per rectum or gross blood on the digital rectal examination. It is important to perform a digital examination in all patients with pelvic fracture as 80–100% of rectal injuries will be diagnosed with this simple maneuver. (1, 2) In addition, information about the integrity of the rectal vault may be obtained by the digital examination, as well as

information about associated injuries to the urethra or spinal cord.(6) Occasionally, it is difficult to distinguish blood from a rectal injury from blood from a nearby external wound.(1)

Initial radiographs are remarkable for the pelvic film which demonstrates bilateral comminuted inferior and superior pubic rami fractures. Chest radiograph and CT of the abdomen were normal.

Endoscopic examination is indicated when suspicion exists for rectal injury.(4) Rigid proctoscopy may be performed, however flexible sigmoidoscopy is the procedure of choice because of difficulties in patient positioning due to their pelvic fracture.(7) Endoscopic imaging will visualize over 90% of rectal injuries.(2)

Anoscopy demonstrates an oozing laceration in the anterior rectum approximately 8 cm above the anal verge.

Because of the association with genitourinary tract injuries, injury to the urethra should be ruled out by a urethrogram, followed by a cystogram to rule out an injury to the urinary bladder.(4, 8) Speculum examination should be performed in female patients to rule out lacerations to the vaginal wall.

Urethrogram and cystogram were performed and were negative for injury.

INITIAL TREATMENT

What general treatment should be instituted initially following an open pelvic fracture?

Pelvic fractures carry a significant mortality, up to 15% for closed fractures and approaching 60% for open fractures.(7) One quarter of deaths following pelvic fracture occur early in the hospital course as a result of hemorrhagic shock.(4) Treatment of the pelvic fracture itself may consist of fracture stabilization by tying a sheet around the pelvis, or early external fixation.(9) Recently, preperitoneal packing of the pelvic fracture has been advocated. (10) Other maneuvers to control the ongoing hemorrhage consist of angiographic embolization or, as a last resort, laparotomy with packing or ligation of bleeding vessels.

In any case, the hemorrhage should be controlled and the patient resuscitated before attention is directed toward diagnosing and treating the rectal injury.(8) The femoral venous route of vascular access should be avoided because rapid infusion may aggravate pelvic bleeding.(4) In addition, these catheters may kink if the patient is placed in stirrups for further examination or wound debridement.

Broad-spectrum antibiotics should be instituted if the patient has a rectal injury or complex soft tissue wound.(2, 4)

Intravenous access had been obtained via upper extremity lines. The patient maintained normal vital signs. Broad-spectrum antibiotics were given.

What treatment should be specifically directed toward the rectal injury?

The principles for repair of blunt rectal injury are essentially the same as those for penetrating rectal injury; specifically, debridement/repair and diversion.

If the rectal injury itself is accessible via anoscope, it should be repaired. In most cases, simple repair is all that is necessary. (8) If the sphincter is involved, it should be repaired as soon as possible. In some cases, the sphincter is destroyed which commits the patient to an abdominal-perineal colon resection. This extensive resection can be delayed until the patient is more stable and other serious injuries have been taken care of.(4)

Diversion of the fecal stream is important, not only to minimize pelvic sepsis associated with the rectal injury itself, but also to allow better care of an associated soft tissue wound. (8) Diversion should be performed as soon as possible, ideally within 48 h of injury (3, 9), as the risk of infection increases if the colostomy is delayed.(11) The stoma may be an end stoma or an end-loop stoma to minimize any distal fecal stream.(4) It is also best if placed in the left upper quadrant, away from any pelvic fixators.(4)

There is some controversy regarding the utility of distal washout to minimize infection.(9, 11) In general, most centers have stopped performing distal washout because it has not been proven to work.

Likewise, there is some controversy surrounding the need for colostomy in any open pelvic fracture. Many authors still recommend it in order to keep the soft tissue wound clean and minimize development of osteomyelitis.(11) Certainly, patients with associated rectal wounds or extensive soft tissue wounds will benefit from diversion.(9)

The case patient was then taken to the operating room and placed in stirrups. Flexible sigmoidoscopy confirmed the presence of a single injury in the anterior rectum at approximately 8 cm from the anal verge. His legs were then taken out of stirrups and a diverting end-loop sigmoid colostomy was performed.

What should be done to manage the associated soft tissue wound?

After initial stabilization, the patient should be taken to the operating room for formal examination of the wound under anesthesia. The patient is ideally positioned in lithotomy position using bucket-type stirrups. These allow for improved positioning after placement of any pelvic fixators.(4) Active bleeding from the soft tissue wound should be controlled directly. If the

Table 15.1 Evidentiary Table of the Management of Rectal Injury with Pelvic Fracture.

Recommendation	Reference	Grade
Diagnostic Testing		
Digital rectal exam	1, 2	1C
Anoscopy	2, 4	1C
Flexible sigmoidoscopy	7	2C
Urethragram/cystogram	4, 8	1C, 2C
Initial Resuscitation		
Fluid resuscitation prior to addressing rectal injury	8	2C
External stabilization of pelvic fracture	9	1C
Preperitoneal packing	10	2B
Treatment of Rectal Injury		
Repair if possible	8	2C
Diverting colostomy	4, 9	1C, 1B
Diverting colostomy	3, 11	2B, 2C
Treatment of Wound		
Daily debridement and irrigation	4	1C

bleeding cannot be controlled surgically, the wound should be packed and resuscitation continued. Once bleeding has been controlled, the wound should be irrigated with a pulsatile irrigation device.(4, 8)

If sigmoidoscopy has not been performed preoperatively, it should be performed at this time, in order to better define the wound. Similarly, vaginal speculum examination may be performed.(4)

Plans should be made to return the patient to the operating room for daily debridement and pulsatile irrigation. If the wound is clean and granulating, it may be closed in stages after the fourth return to the operating room.(4)

What adjuncts to treatment are there?

Broad-spectrum antibiotics are useful for the first 48–72 h. If the soft tissue wound is extensive, enteral feeding access via jejunostomy or nasal-duodenal tube is important. This allows the patient to receive needed nutrition to help healing.(4)

OUTCOMES

What is the long-term outcome for rectal injury following an open pelvic fracture?

The most common cause of mortality among those patients who survive the initial resuscitation is sepsis.(4) Up to 50% of late deaths are due to infectious complications.(9) The mortality of all open pelvic fractures is 3%, however the presence of a rectal injury increases the mortality to 77%.(3)

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16 Abdominal aortic injury
Gainosuke Sugiyama and Asher Hirshberg

A 16-year-old boy is brought to the emergency department (ED) after having sustained a single gunshot wound to the upper abdomen. He is disoriented and combative; his skin is cold and clammy. He is hypotensive (SBP 80) and tachycardic (HR 146) with a distended tender abdomen. The entry wound is above and to the left of the umbilicus; there is no exit wound. Two large-bore peripheral IV lines are inserted, and the patient undergoes a rapid endotracheal intubation. A plain abdominal X-ray shows the bullet immediately to the right of L3. The chest X-ray is unremarkable. The patient is taken emergently to the operating room (OR).

At laparotomy, approximately a liter of blood and clots is found in the peritoneal cavity. The bowel is rapidly eviscerated to the patient's right; the blood is evacuated and a large central retroperitoneal hematoma is noted beneath the transverse mesocolon with bright red blood oozing from a hole in the left retroperitoneum. There are six bullet holes through the eviscerated small bowel.

At this point, the patient becomes profoundly hypotensive. The supra-celiac aorta is manually compressed through a hole in the lesser omentum and then formally clamped through the right diaphragmatic crus. The small bowel is reflected to the right and upward, and the retroperitoneal hematoma is entered in the midline of the posterior retroperitoneum to reveal a through-and-through gunshot injury to the anterior aspect of the middle portion of the infrarenal aorta. The supra-celiac aortic clamp is then repositioned below the renal arteries, just proximal to the injury, and an angled vascular clamp is applied immediately below the injury to achieve definitive control. The bullet holes are joined to create a single transverse laceration. The laceration is carefully debrided and then repaired transversely with a running 3:0 polypropylene suture, and the repair is meticulously covered with omentum.

At this point, the patient's core temperature is 34°C and his pH is 7.11. He received 10 units of pRBC, 8 units of FFP, and 700 ml of autotransfused blood. Two segments of small bowel carrying the six perforations are rapidly stapled across proximally and distally without resection, and the abdomen is temporarily closed using the vacuum pack technique. Four hours after surgery the patient is noted to have tense compartments in both lower extremities and undergoes bilateral four-compartment fasciotomies at the bedside.

The abdomen is re-explored 36 h later, with resection of two short bowel segments and a stapled end-to-end anastomosis. The open abdomen is closed on postoperative day 4, and the fasciotomy wounds are closed on postoperative day 8. The patient is discharged home on postoperative day 17. His ankle–brachial index on discharge is 0.9 bilaterally. He is seen in the outpatient clinic twice for laparotomy wound care, and then is lost to follow up.

WHAT IS THE CLINICAL PRESENTATION OF ABDOMINAL VASCULAR TRAUMA?

Most major abdominal vascular injuries are caused by penetrating trauma and result in a retroperitoneal hematoma and varying degrees of free intraperitoneal bleeding. Due to the deep midline retroperitoneal location of the major abdominal vessels, these injuries almost never occur in isolation, and trauma to other abdominal organs along the path of the wounding missile is the rule rather than the exception.[1]

Patients with free intraperitoneal bleeding usually present in profound shock.[2] Those with contained retroperitoneal hematoma, especially with an injury to a large vein, may be hemodynamically stable at presentation. Occasionally, a femoral pulse may be absent if an iliac artery has been severed. The vast majority of patients with penetrating trauma to the abdominal aorta is grossly unstable at presentation, and roughly one in five present in extremis and undergo a resuscitative ED thoracotomy.[3]

Trauma to the abdominal great vessels accounts for roughly 30% of peripheral vascular injuries.[4, 5] The most commonly injured vessels are the aorta and inferior vena cava (IVC). The chance of finding a vascular injury during laparotomy for a gunshot wound (1 in 4) is much higher than during laparotomy for a stab (1 in 10).

Unless the patient is in extremis, it is worthwhile to obtain shock room X-rays of the chest and abdomen to delineate the bullet trajectory because it helps direct the exploration to the relevant parts of the abdominal cavity and may also provide a useful clue to the presence of abdominal vascular injury. A bullet that crosses the abdominal midline or overlays the spine (the so-called transabdominal or trans-axial trajectory) in a hypotensive patient is associated with a high likelihood of abdominal vascular injury.[6]

In the case patient, the indication for immediate laparotomy is obvious. There is no time (nor need) for a diagnostic workup, and the precise diagnosis is made intra-operatively. Time should not be wasted on fluid resuscitation or on attempts to "stabilize" the patient, who has sustained a trans-axial gunshot wound.

WHAT ARE THE IMMEDIATE OPERATIVE PRIORITIES?

Gaining access to the injured cavity and temporary bleeding control are the immediate operative priorities. Access is gained through a midline laparotomy incision. Evisceration of the small

bowel allows evacuation of intraperitoneal blood and a quick assessment of the injured area. Free hemorrhage must be controlled immediately, using manual pressure (for arterial bleeding) or packing (for venous hemorrhage). Formal vascular exposure and control will be obtained later, as blind clamping in a pool of blood is ineffective and may cause iatrogenic injury. A contained retroperitoneal hematoma may allow some time to rapidly complete the abdominal exploration, control spillage of intestinal content, and, most importantly, organize the attack on the injury.(7)

Once bleeding has been temporarily controlled and before the injury is exposed and addressed directly, it is prudent to pause the operation and spend time on optimizing the OR team effort. Sufficient quantities of blood products are brought to the OR in preparation for massive blood loss, rapid infusion and autotransfusion devices are hooked up and activated, a full vascular tray is deployed, and exposure is improved.(7) Only then, when everything is prepared and the team is ready, should the vascular repair begin.

HOW TO ACHIEVE PROXIMAL AORTIC CONTROL?

A cardinal principle of vascular trauma is to obtain proximal control before entering a hematoma around an injured vessel. Clamping the abdominal aorta is a time-honored maneuver traditionally used both for obtaining global proximal control of the aorta (and its major branches) and as an adjunct to resuscitation in a profoundly hypotensive patient with intra-abdominal hemorrhage.(8)

The location and technique for obtaining proximal control is dependent on the level of injury and extent of the ensuing hematoma. Proximal control for distal aortic injuries can be obtained below the transverse mesocolon. In this case, the small bowel is eviscerated to the right and upward, the ligament of Treitz is incised and the duodenum is mobilized laterally, then the posterior peritoneum is incised in the midline below the transverse mesocolon to gain access to the infrarenal aorta and clamp it.

For more cephalad injuries or when performed as a resuscitative maneuver, proximal control of the aorta must be achieved at the supra-celiac level. This is performed by bluntly creating an opening in the lesser omentum and retracting the stomach to the left to expose the posterior retroperitoneum and the right crus of the diaphragm.(9) Digitally separating the fibers of the right crus immediately above the clearly palpable aortic pulsation creates enough space on both sides of the aorta to accommodate an aortic clamp. With this technique, the clamp is applied to the lowermost portion of the descending thoracic aorta, thus avoiding the dense periaortic tissue enveloping the upper abdominal aorta. The route used to place the clamp, however, is transabdominal.

Supra-celiac clamping can be facilitated by mobilizing the abdominal portion of the esophagus. To that end, the left lateral hepatic lobe is retracted to the right using a deep flat-bladed retractor, the visceral peritoneum overlying the esophagus just above the gastroesophageal junction is incised, and the esophagus is encircled digitally by blunt circumferential dissection. A large Penrose drain is then placed around the esophagus, enabling lateral traction of the mobilized esophagus to the left. This provides access to the right diaphragmatic crus and the underlying aorta.

Often performed blindly in a pool of blood, supra-celiac clamping is not straightforward, especially in inexperienced hands. It may cause iatrogenic injury to adjacent structures (such as the esophagus or the celiac axis), or fail to gain purchase on the aorta altogether. A safer and simpler option is manual compression of the aorta against the spine through a hole in the lesser omentum.(7, 8)

Another option for proximal control of the supra-celiac aorta is to perform a left anterolateral thoracotomy and clamp the lower descending thoracic aorta in the chest, as described elsewhere in this book.

> In the case patient, supra-celiac aortic compression through the lesser sac was used as a resuscitative maneuver. Formal supra-celiac clamping was necessary because the hematoma extended to the transverse mesocolon, prohibiting safe rapid placement of an infrarenal aortic clamp. Only when the hematoma was entered and the injury identified was the supra-celiac clamp repositioned below the renal arteries.

HOW TO GAIN ACCESS TO THE ABDOMINAL GREAT VESSELS?

The key to gaining access to the abdominal great vessels and their major branches is to rotate the overlying intraperitoneal structures medially, off the midline vascular structures. Depending on the target vessel, this medial rotation can be done from the right or left side.

Left-sided medial visceral rotation (Mattox maneuver) (10) (Figure 16.1) exposes the entire length of the abdominal aorta from the diaphragm to the aortic bifurcation and is the only way to gain rapid access to the para-visceral aortic segment (from the diaphragmatic hiatus to the renal arteries). Incising the lateral peritoneal attachment of the sigmoid and descending colon guides the dissection into the correct plane immediately on the psoas muscle. Dissecting bluntly in this plane is greatly facilitated by the presence of a central retroperitoneal hematoma. As the back of the dissecting hand sweeps on the muscles of the posterior abdominal wall in a cranial direction behind the left colon, kidney, spleen and tail of pancreas, all these left-sided viscera (as well as the fundus of the stomach) are rotated to the midline, providing access to entire length of the abdominal aorta (8), as well as to the superior mesenteric and left renal vessels.

Right-sided medial visceral rotation is performed in three successive steps, each providing progressively better exposure of the retroperitoneum.(8) The first step is incising the posterior peritoneum just lateral to the duodenal loop to mobilize the pancreato-duodenal complex medially (Kocher maneuver). Carrying this peritoneal incision caudally into the white line of Toldt allows mobilization of the entire right colon, the second of the three steps. This exposes the IVC, right iliac vessels, and right renal hilum. Continuing the peritoneal incision around the cecum along line of fusion of the small bowel mesentery to the posterior peritoneum, from the cecum to the ligament of Treitz, completes the third and final step of the medial
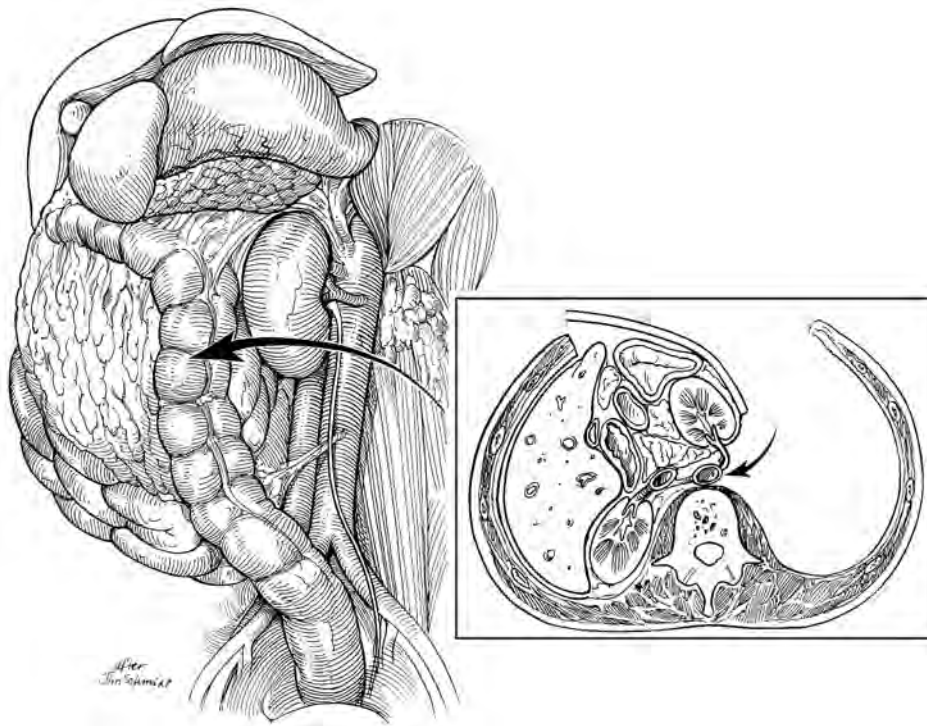
Figure 16.1 Left-sided medial visceral rotation (Mattox maneuver). Artwork by Jan Redden, © Kenneth L. Mattox, MD, Houston, Texas, reproduced with permission.
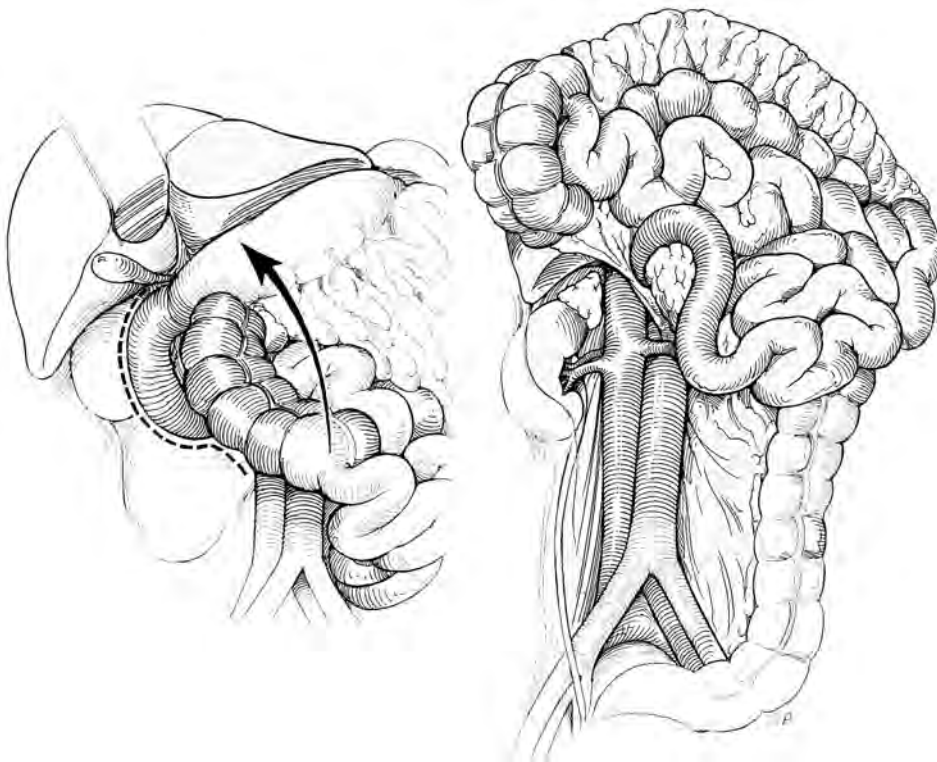

Figure 16.2 The completed Braasch–Cattell maneuver. Artwork by Jan Redden, © Kenneth L. Mattox, MD, Houston, Texas, reproduced with permission.

rotation. It allows reflection of the small and large bowel out of the abdomen and unto the chest (Figure 16.2). This is the Cattell–Braasch maneuver.(11) Originally described as a technique to access the third and fourth portions of the duodenum, it provides the widest possible exposure of retroperitoneal structures, including the infrarenal aorta and vena cava, bilateral iliac vessels, and both renal vascular pedicles.

MUST EVERY RETROPERITONEAL HEMATOMA BE EXPLORED?

The anatomic location of a retroperitoneal hematoma and the mechanism of injury (penetrating vs. blunt) guide the decision to explore it.(12) The retroperitoneum is divided into three zones: the midline retroperitoneum (Zone 1), the lateral perinephric area (Zone 2), and the pelvic retroperitoneum (Zone 3). The transverse

mesocolon divides Zone 1 into supra-mesocolic and infra-meso-colic sectors. A hematoma in the former is seen behind the lesser omentum, pushing the stomach forward, whereas bleeding in the latter pushes the small bowel mesentery forward, much like a ruptured abdominal aortic aneurysm *(Figure 16.3)*.

Any hematoma in Zone 1 mandates exploration for both penetrating and blunt trauma because of the high likelihood and unforgiving nature of vascular injuries in this area, which contains the aorta and the proximal portions of its major visceral branches. (12) Proximal control is initially obtained at the diaphragmatic hiatus, and the injured segment is exposed through a left-sided medial visceral rotation (for a supra-mesocolic hematoma) or by eviscerating the small bowel to the right and upward and incising the posterior peritoneum in the midline below the transverse mesocolon (for an infra-mesocolic hematoma).(8)

A retroperitoneal hematoma in Zone 2 should be explored if expanding or pulsating. A stable perinephric hematoma, especially due to a blunt mechanism, is best left unexplored because opening Gerota's fascia often leads to loss of the kidney. Proximal control of the renal hilum is achieved either by opening the posterior peritoneum over the aorta and selectively looping the renal vessels in the midline, or (more commonly) by rapidly mobilizing the injured kidney to the midline and clamping the entire renal hilum. A hematoma in Zone 3 should be explored for penetrating trauma but not for blunt, unless there is clinical suspicion of an iliac vascular injury.

> In the case patient, access to the injured infrarenal aortic segment was gained using a limited retroperitoneal exposure in a manner similar to exposing an abdominal aortic aneurysm. However, some surgeons routinely perform a full Cattell–Braasch exposure in this situation while others use it only if the more limited exposure proves inadequate.

HOW TO ACHIEVE DEFINITIVE CONTROL OF AN AORTIC INJURY?

Supra-celiac aortic clamping allows enough proximal control to enter the hematoma and visualize the injury, but does not provide a dry operative field for exploration and repair because of vigorous back bleeding. Definitive control is achieved by repositioning the proximal aortic clamp closer to the injury and applying a distal clamp immediately below it on the distal aorta or common iliac vessels. Back bleeding from lumbar arteries must also be controlled. The injury can then be carefully explored to define the extent of the damage.

WHAT ARE THE VASCULAR REPAIR OPTIONS?

A simple laceration (typically a stab wound) is usually closed using a lateral repair with a 3:0 or 4:0 polypropylene suture. When the damage is more extensive (typically a gunshot injury) with substantial loss of aortic wall that prohibits a lateral repair, the most straightforward option is to insert a short interposition graft. The abdominal aorta does not lend itself well to primary end-to-end anastomosis because it cannot be mobilized, and patch angioplasty is rarely used.
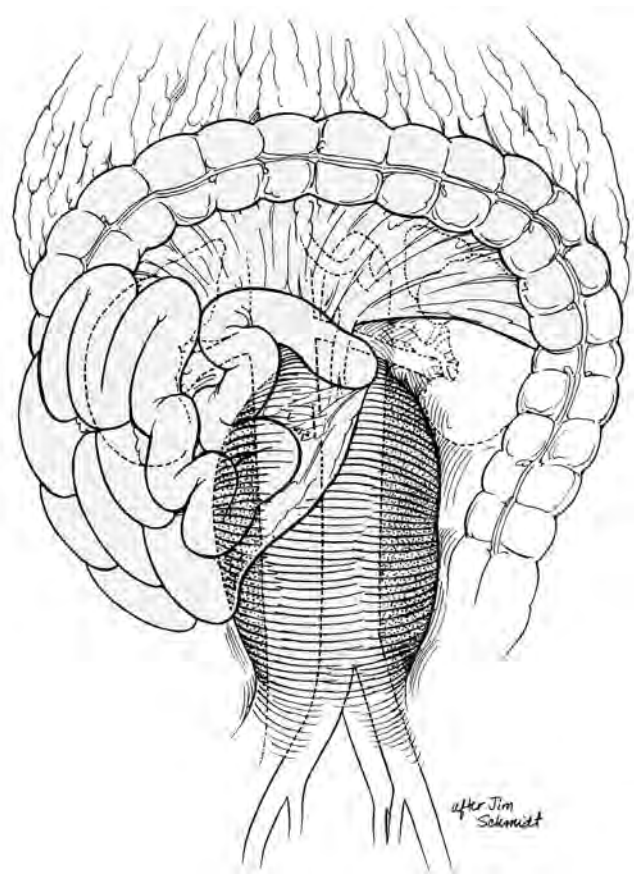
Figure 16.3 Midline infra-mesocolic retroperitoneal hematoma. Artwork by Jan Redden, © Kenneth L. Mattox, MD, Houston, Texas, reproduced with permission.

The aorta of young patients is surprisingly small, very soft and tears easily. A conscious effort should be made to insert a graft that is slightly larger than the injured vessel, typically a size 14–18 mm synthetic graft.

Once the repair has been completed, it is crucial to isolate the vascular suture line from the peritoneal cavity, which is often contaminated from bowel perforations. An effective technique is to separate the greater omentum off the transverse colon along the bloodless line, create a hole in the transverse mesocolon to the left of the middle colic vessels, and swing the free greater omentum through that mesenteric defect into the infra-mesocolic compartment, to cover the aortic repair.

> Despite being a gunshot injury, the case patient sustained a small-caliber through-and-through wound with limited aortic wall destruction. This injury was amenable to lateral repair without the use of prosthetic material.

IS THERE A "DAMAGE CONTROL" OPTION FOR AORTIC INJURIES?

There are no good damage control options for an abdominal aortic injury. There is a single report from 1948 in which a large aortic defect from a gunshot wound was bridged by a vitallium tube secured with umbilical tape.(13) The patient survived and was

discharged home with the tube in place. There is no other report of a survivor following temporary shunt insertion to bridge an injured abdominal aorta. Richardson et al. (14), who emphasized the role of damage control in the operative management of aortic injuries, reported two patients in whom the aorta was ligated during the initial operation. Both underwent a delayed axillofemoral bypass to revascularize the lower extremities.

While the aortic injury generally requires definitive repair, associated injuries are often addressed using damage control tactics. By the time the injured aorta is controlled and repaired, the patient has typically had massive blood loss with a corresponding severe physiological insult. Under these circumstances, control of spillage is a priority, but there is no time for formal resection and reconstruction of injured hollow organs. Similarly, the distended edematous bowel, the swollen non-compliant abdominal wall, and the need for a rapid "bail out" usually prohibit formal abdominal closure in favor of a temporary solution.(14)

> The case patient underwent a damage control laparotomy with temporary control of spillage and temporary abdominal closure. Definitive reconstruction of the GI tract was done 36 h later. Definitive abdominal closure was achieved 5 days after the index laparotomy.

HOW TO APPROACH COMBINED INJURIES TO THE AORTA AND VENA CAVA?

Roughly one in three or four patients with abdominal aortic trauma will have an associated injury to the IVC.(2, 15) Combined injuries to the supra-mesocolic great vessels are especially lethal because both the aorta and IVC are difficult to access, control, and repair around and above the renal vessels.

The key technical maneuver for repair of combined infra-mesocolic injuries is a full Cattell–Braasch maneuver to completely expose the infra-mesocolic retroperitoneum. The aorta is controlled as described above, while the IVC is controlled by applying direct pressure above and below the injury. The most difficult area to access in the infrarenal IVC is the bifurcation, where deliberate transection of the overlying right iliac artery may be the only way to gain access to the venous injury.(16)

WHAT ARE THE IMMEDIATE POSTOPERATIVE CONCERNS?

In patients with abdominal vascular trauma, the immediate postoperative priorities are correcting the consequences of exsanguinating hemorrhage and massive transfusion, and restitution of the patient's physiological envelope.(17) Swift correction of hypothermia and dilutional coagulopathy is critical.

Postoperative hemorrhage (which usually becomes rapidly apparent if the abdomen is open) should prompt an urgent re-exploration. Attention is first turned to the area of injury, where inadequate hemostasis in and around the vascular repair is a common source of bleeding. Missed injuries (14) and iatrogenic trauma (e.g., splenic laceration during left-sided medial visceral rotation) are other sources of surgical bleeding found at re-laparotomy.(18)

Another immediate postoperative concern is distal ischemia. The first priority in aortic injuries is control of hemorrhage, and this is sometimes achieved at the cost of compromised distal flow.(14) Lateral repair of an aortic laceration may result in hemodynamically significant stenosis with distal ischemia, or even in distal aortic thrombosis. Use of a small-diameter graft may also lead to aortic narrowing. Therefore, any evidence of significant distal ischemia in the postoperative period in a stable patient should prompt an urgent angiography to delineate the reconstructed area.

The risk of compartment syndrome must be always kept in mind. If the abdomen is closed, bladder pressures should be closely monitored for evidence of intra-abdominal hypertension. Abdominal compartment syndrome may also occur in an "open" abdomen where the viscera are contained by a temporary closure device. The combination of prolonged hypotension and long aortic cross-clamp time sets the stage for compartment syndrome of the lower extremities, both below and above the knee.

> The case patient developed compartment syndrome of the lower extremities despite only 35 minutes of aortic cross-clamp time. This occurs more commonly following prolonged aortic clamping (as may be required for graft interposition or when the reconstruction has to be redone) or prolonged hypotension due to delays in obtaining vascular control or addressing associated injuries. Under these circumstances, a good case can be made for "preemptive" empirical fasciotomies.

WHAT IS THE RISK OF INFECTION?

The very frequent association of abdominal vascular and hollow organ injuries raises obvious concerns of infection at the aortic repair site. Good data on the incidence of postoperative graft infection are lacking (see below), but the impression of experienced trauma surgeons is that it is an uncommon occurrence. Furthermore, although the aortic reconstruction may involve the use of synthetic graft material in a contaminated field, there is no good extra-anatomic alternative to direct aortic reconstruction in these critically injured patients. Ligation of the aorta with delayed extra-anatomic reconstruction is a valid consideration in extreme situations (such as heavy fecal soiling of the retroperitoneum or a patient in profound shock). Washing out the aortic repair site, isolating it from the injured bowel, and meticulous coverage of the vascular suture lines as described above are thought to reduce the risk of infection and prevent the later development of aorto-enteric fistulae.

WHAT IS THE OUTCOME OF ABDOMINAL AORTIC INJURIES?

Penetrating abdominal aortic injuries are associated with exceptionally high mortality rates: only about one in four patients survives (1–3, 10, 19, 21), with higher survival rates for trauma to the infrarenal aorta as compared to the supra-renal segment (1, 2),

and for stabs as compared than gunshot wounds.(3) In the largest published series of combined aorta–IVC injuries, only 7 of 29 patients survived.(15)

When the retroperitoneal tamponade is lost with free hemorrhage into the peritoneal cavity, the prognosis is especially bleak. (19, 22) Shock on admission (1, 2, 19) is a grave sign, and the need for resuscitative ED thoracotomy is practically universally fatal with no long-term survivors.(3, 20) When the hematoma is contained and there is no exsanguination before obtaining vascular control, the chances of survival are roughly 50%, still a very high mortality rate.(20) Interestingly, the results reported in series from the last two decades are very similar to those reported in the 1970s and the improvements in hospital trauma systems and services have had no effect on the outcome of abdominal aortic injuries.(3)

There is only one report on long-term follow-up in patients with abdominal aortic trauma who underwent lateral repairs.(23) Five of eleven patients followed for up to 15 years after their injury had abnormal ankle–brachial indexes and aortic calcification at the repair site on CT scan, indicating possible predisposition to accelerated local atherosclerosis.

A NOTE ON LEVELS OF EVIDENCE

It is important to keep in mind that all series of abdominal aortic injuries in the literature are retrospective case series.(1, 2, 10, 14, 15, 19, 21, 22) Other authors incorporated aortic injuries within large series of abdominal vascular trauma.(3, 5, 20) Aortic injuries are uncommon and have never been subject to prospective study. Thus there is no Level 1 or 2 data comparing various technical options and approaches.

Since the outcome of abdominal aortic injuries is reported mostly in terms of overall survival rather than morbidity, good data on the incidence of specific complications are conspicuously absent from the trauma literature. While some complications such as lower extremity ischemia (1, 14) are occasionally mentioned in passing, the incidence of distal ischemia, postoperative bleeding, or compartment syndrome remains unknown.

Similarly, infection of the repair site is reported sporadically by some authors (14), but there is no data on the incidence of such infections or on their management even in modern well-documented series.(14, 19–21)

In view of the very high mortality and extreme urgency of the clinical situation, it is very unlikely that recommendations for the operative management of abdominal aortic trauma and the prevention of complications will ever be evidence based.

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17 Blunt pelvic fracture with hemoperitoneum
John H Adamski II and Thomas M Scalea

A 48-year old is struck by a low-speed automobile in a parking garage where she was pinned against a cement wall. She is brought to the emergency room in hemorrhagic shock with a systolic blood pressure of 85 mmHg, heart rate of 136, and a respiratory rate of 32 breaths per minute. The patient is confused, has evidence of a scalp contusion, unstable pelvic fracture, and left lower extremity deformity splinted in place. Airway control is obtained by endotracheal intubation and intravenous fluids provided from bilateral large-bore intravenous catheters. Physical exam reveals equal bilateral breath sounds; a soft, flat abdomen with an unstable pelvis on palpation; and a deformed left lower extremity with good pulses. A pelvic binder is placed, a focused abdominal sonography for trauma (FAST) examination performed, and X-rays obtained. Hemodynamic parameters begin to normalize after 3 l of crystalloid solution and 2 units of packed red blood cells were infused. The FAST examination shows an empty pericardium with good cardiac wall motion and free fluid in the pelvis. Chest X-ray is normal, and A/P pelvis X-ray shows an "open book" pelvis fracture with 6 cm of diastases. A nondisplaced left tibia fracture is identified on extremity radiographs. With improved hemodynamics, the patient receives a CT head, CT c-spine, CT chest, and CT abdomen/pelvis with IV contrast. A CT cystogram is also obtained because hematuria is observed after urinary catheter placement. CTs are normal except for the pubic symphysis diastases of 6 cm, right inferior pubic ramus fracture, sacroiliac joint widening, an active blush in the right pelvis, a large retroperitoneal hematoma, and a small extraperitoneal bladder rupture. Resuscitation is continued and the patient kept warm as an interventional radiologist is consulted to perform pelvic angiography. Orthopedics is consulted for potential placement of an external fixator. Angiography identifies active arterial bleeding from two branches of the right internal iliac artery. Each of these bleeding vessels is selectively embolized with the absence of extravasation on follow-up angiography. Clinically, the patient begins to improve and The patient is admitted to an intensive care bed for ongoing resuscitation and assessment. Hemodynamically she remains stable, clears her lactic acidosis, and undergoes open reduction and internal fixation (ORIF) of her pelvis and intramedullary nail (IMN) of her left tibia on hospital day 1. She is extubated 48 h after surgery and discharged to an acute rehabilitation facility on hospital day 9.

EPIDEMIOLOGY OF PELVIC FRACTURES

The pelvic ring has no inherent stability without support from ligamentous structures. Pelvic ring fractures account for approximately 3% of all skeletal fractures.(1, 2) In the elderly, these fractures are a result of low impact falls from standing and can be managed conservatively without complication.(3) Nevertheless, most pelvic fractures are a result of high-force blunt trauma such as automobile crashes, motorcycle crashes, automobile–pedestrian collisions, and falls from height. Unstable pelvic fractures as a result of major forces are associated with a mortality of approximately 8–50%.(4–11) Concomitant injuries to the head and/or thoracoabdominal cavity can increase morbidity and mortality approximately fivefold.(12, 13) Associated pelvic hemorrhage is a significant source of mortality in these patients. (14–18) Accordingly, hypotension on arrival to the emergency department is associated with a mortality of approximately 50%. (19–22) Hence, immediate identification, transport, and treatment of these patients are essential elements to good therapy. Likewise, open pelvic fractures are associated with a mortality of 30–50% and need to be identified to improve overall outcome. (23–25) At present, pelvic fractures are not considered gender specific; however, males tend to account for more injuries as a result of automobile crash distribution. Similarly, age to injury distribution analysis shows a higher prevalence of pelvic fractures for adults involved in car crashes in contrast to a higher prevalence of childhood pelvic fractures as a result of automobile–pedestrian crashes. Overall, pelvic fractures are associated with high degree of morbidity, mortality, and functional disability.

PELVIC FRACTURE CLASSIFICATION

As a bony structure, the pelvic is a ring made up of the ilium, ischium, pubis, and sacrum. The posterior arch of the pelvic ring transmits weight-bearing forces from the lumbar spine to the acetabulum when standing and ischium when sitting. The anterior arch serves as a strut to preserve the shape of the pelvic ring. Transversely and vertically oriented ligaments uphold the stability of the pelvis. The pelvis has a rich venous plexus and arterial blood supply which can be disrupted by resultant high-energy forces. Similarly, the bladder, urethra, rectum, and/ or vagina in females may be injured in association with a pelvic fracture. Historically, pelvic fractures have been classified in terms of pelvic stability. Pennal and Tile were the first to classify pelvic fractures according to the force that caused the injury and pelvic stability (26; Table 17.1). The Tile system of classification identifies the direction of injuring force and resultant stability of the pelvic ring. Pelvic fractures are classified as being stable (Type A), rotationally unstable, posteriorly and anteriorly stable (Type B), or rotationally unstable, posteriorly and anteriorly unstable (Type C). Young and Burgess later refined this classification to predict the degree of pelvic injury and hemorrhage, as well

as associated injuries (27–29; Table 17.2). Anatomic mechanism of injury is identified with four types of ring disruption in relation to the degree of fracture extent and severity. Pelvic injuries are classified as anterior–posterior compression fractures (APC), lateral compression fractures (LC), vertical shear injuries (VS), and combined mechanical fractures (CM). Numerous studies have identified lateral compression injuries followed by APC fractures as being most common, respectively. AP compression fractures and vertical shear injuries have a higher incidence of pelvic vascular injury and hemorrhage.(4, 25)

> The case patient would have a Tile Type B1 fracture or a Young and Burgess APC3 fracture.

PRE-HOSPITAL AND EMERGENCY DEPARTMENT TREATMENT

Pre-hospital care is governed by various federal, state, and local guidelines to provide lifesaving emergency care, stabilization, and transport to a receiving medical facility. Accordingly, the ABCDs are managed to optimize transport. Once life-threatening conditions are addressed and the patient immobilized with cervical spine stabilization, the mechanism of injury and physical exam should increase a provider's suspicion of a potential pelvic fracture. Intravenous access should be obtained and intravenous fluid administered. If a pelvic fracture has been identified, excess manipulation should be avoided. Although the use of medical antishock trousers (MAST) have not been shown to decrease mortality in the polytrauma patient, and fallen out of use because of complications in associated thoracic injuries, they can help to reduce pelvic volume and facilitate tamponade of retroperitoneal hematomas.(30) However, rapid transport of the patient to a trauma facility remains the mainstay of pre-hospital care.

Early management in the emergency department or trauma resuscitation unit is designed to facilitate the identification of emergency situations that require immediate intervention. The hypotensive patient is always a diagnostic challenge but can be assessed via the use of clinical skills and various diagnostic tools. Life-threatening causes of hypotension need to be evaluated and managed rapidly. These include airway obstruction, cardiac tamponade, tension pneumothorax, massive hemothorax, and hemorrhage.(31) A patient with an unstable pelvic fracture can present with a plethora of signs and symptoms. These include palpable pelvic tenderness, palpable pelvic instability, limited hip adduction, a scrotal hematoma, hematuria, urethral, vaginal or rectal bleeding, and neurovascular deficits of the lower extremities.

Bedside ultrasonography is a valuable adjunct to determine if there is pericardial or intra-abdominal free fluid. Initial trauma radiographs should be obtained of the cervical spine, chest, and pelvis. Although temporary pelvic stabilization may be performed before radiographs via a pelvic immobilizer or a wrapped sheet, its utility can be confirmed by finding pelvic diastases on X-ray. (32) Intravenous resuscitation should be aggressively performed as sources of hypotension are elucidated. Additional diagnostic studies will be guided by the patient's hemodynamic status and

Table 17.1 Injury Classification According to the Young–Burgess system.(28, 29)

Classification	Injury Pattern
Lateral Compression (LC)	Transverse fracture of pubic rami, ipsilateral, or contralateral to posterior injury I—sacral compression on impact side II—iliac wing (crescent) fracture on impact side III—LCI or LCII injury on impact side; contralateral open book (APC) injury
Anterior to Posterior Compression (APC)	Symphyseal diastasis or longitudinal rami fractures I—widening of pubic symphysis or anterior SI joint; intact but stretched anterior SI, sacrotuberous, and sacrospinous ligaments, and intact posterior SI ligaments II—widened anterior SI joints; disrupted anterior SI, sacrotuberous, and sacrospinous ligaments; intact posterior SI ligaments III—total SI disruption accompanied by lateral displacement, disrupted anterior SI, sacrotuberous, and sacrospinous ligaments, and disrupted posterior SI ligaments
Vertical Shear (VS)	Symphyseal diastasis or vertical displacement in anterior and posterior directions, typically through SI joint, but occasionally through the sacrum or iliac wing
Combined Mechanisms (CM)	Combined injury pattern, with LC/VS being the most frequent

resource availability. CT scanning offers an accurate assessment of intracranial, thoracic, and abdominal–pelvic injuries including solid organ damage and the presence of blood. In addition, three-dimensional reconstruction of the pelvis provides good anatomical evaluation of additional fracture sites. Despite advances in resolution, CT scanning still requires mobilization and transport of the patient, as well as time to perform and process the images. Hence, hemodynamic stability needs to be monitored.

Additional studies can be orchestrated in the emergency department. If signs of a potential urethral injury are present, a retrograde urethrogram should be obtained before placing a urinary catheter.(33) The presence of hematuria in the setting of a pelvic fracture should raise suspicion of a potential bladder rupture.(34) A cystogram can be obtained if CT is utilized. Although CT would help identify additional injuries, the need for orthopedic and interventional radiology consultants should be made early to facilitate placement of an external fixator or performance of angioembolization, respectively. Patients with pelvic fractures who remain unstable despite adequate resuscitation must be assessed for the need of surgical intervention.(35) Additional modalities, such as diagnostic peritoneal lavage or tap, FAST, and the expertise of a trauma surgeon can assist in this decision.

Table 17.2 Injury Classification According to a Modified Tile System.(10)

Modified Title Classification System
Type A—Stable, Posterior Arch Intact
A1—Posterior arch intact, fracture of innominate bone (avulsion)
A1.1—Iliac spine, A1.2—Iliac crest, A1.3–Ischial tuberosity
A2—Posterior arch intact, fracture of innominate bone (direct blow)
A2.1—Iliac wing fractures, A2.2—Unilateral fracture of anterior arch, A2.3–Bifocal fracture of anterior arch
A3—Posterior arch intact, transverse fracture of sacrum caudal to S2
A3.1—Sacrococcygeal dislocation, A3.2—Sacrum undisplaced, A3.3—Sacrum displaced
Type B—Incomplete disruption of posterior arch, partially stable, rotation
B1—Exteral rotation instability, open-book injury, unilateral
B1.1—Sacroiliac joint, anterior disruption, B1.2—Sacral fracture
B2—Incomplete disruption of posterior arch, unilateral, internal rotation (Lateral compression)
B2.1—Anterior compression fracture, sacrum, B2.2—Partial sacroilaic joint fracture, subluxation, B2.3—Incomplet posteior iliac fracture
B3—Incomplete disruption of posterior arch, bilateral
B3.1—Bilateral open-book, B3.2—Open-book, lateral compression, B3.3—Bilateral lateral compression
TypeC—Complete disruption of posterior arch, unstable
C1—Complete disruption of posterior arch, unilateral
C1.1—Fracture through ilium, C1.2—Sacroilaic dislocion and/or fracture disloction, C1.3—Sacral fracture
C2—Bilateral injury, one side rotationally unstable, one side vertically unstable
C2.1—Fracture through ilium, C2.2—Sacroiliac dislocation and/or fracture dislocation, C2.3—Sacral fracture
C3—Bilateral injury, both sides completely unstable
C3.1—Extrasacral on both sides, C3.2—Sacral one side, extrasacral other side, C3.3 Sacral both sides

The case patient was managed in the field by emergency services and transported to the emergency department in a timely fashion. Acute life-threatening injuries were evaluated and managed appropriately. Confusion with outward signs of head trauma, as well as the presence of hypotension with an unstable pelvic fracture and long bone fracture, promoted the need for a definitive airway and further assessment. Aggressive intravenous resuscitation was instituted with good results. The unstable pelvis was temporary treated with a pelvic binder. Necessary radiographs were obtained. FAST identified free fluid in the pelvis in a hemodynamically responsive patient.

IS THE FREE FLUID FROM THE ABDOMEN OR THE PELVIS?

Although tests such as chest X-ray, diagnostic peritoneal lavage, ultrasound, and CT scan have proven useful for the diagnosis of thoracic (CXR) and intra-abdominal (diagnostic peritoneal lavage [DPL], US, CT) hemorrhage, there is no study to expeditiously confirm pelvic ring disruption and associated hemorrhage. Similarly, the patient with pelvic fracture and potential abdominal injury presents a diagnostic and therapeutic challenge to the physician. On primary examination, life-threatening causes of hypotension such as airway obstruction, cardiac tamponade, tension pneumothorax, massive hemothorax need to be diagnosed while actively resuscitating the patient. Although, A/P pelvic X-ray can identify almost all pelvic fractures, it does not identify active hemorrhage. Nevertheless, certain fracture patterns (APC, VS) are predictive of pelvic hemorrhage.

In most medical centers, current practice utilizes the FAST for the evaluation of free fluid within the pericardial sac, hepatorenal fossa, splenorenal fossa, and pelvis.(36, 37) Although it is quite specific for the detection of free fluid in the abdomen, it is limited by the inability to detect isolated injuries to the bowel and retroperitoneum. Immediate operation is wise for the hypotensive, blunt trauma patient with a positive FAST.(11) Accordingly, it is estimated that approximately 30% of pelvic trauma patients have associated intra-abdominal injuries.(36) Nontherapeutic laparotomy has been correlated to an increase in hemorrhage-related mortality in 50% of patients with pelvic fractures.(12) Increased mortality and associated hemorrhage has been attributed to increased pelvic volume, loss of tamponade, and disruption of contained retroperitoneal hematomas.(13, 38)

Studies by Chiu et al. and Ballard et al. also suggest an elevated false-negative rate for FAST in patients with suspicion for pelvic fracture.(39, 40) These events have led to a favoring of IV contrast-enhanced CT scanning to evaluate intra-abdominal free fluid when hemodynamically possible. Fundamentally, the identification of free fluid by FAST as a potential source of hemorrhage has not changed; however, the use of adjunct modalities has helped to direct therapeutic options. The indications for laparotomy for a hypotensive pelvic fracture patient with free fluid on FAST despite aggressive resuscitation remain the same as a hypotensive patient without a pelvic fracture and a positive FAST. Additional modalities, such as diagnostic peritoneal lavage and diagnostic peritoneal tap, have been studied to help evaluate free fluid in the abdomen.

However, Hubbard et al. reported a false-positive rate of 29% for supraumbilical diagnostic peritoneal lavage in the patient with a pelvic fracture.(41) It is believed that red blood cell diapedesis and hematoma disruption may contribute to this finding. Many authors advocate laparotomy in patients with pelvic fractures who have gross blood on DPL as opposed to external pelvic stabilization followed by additional diagnostic modalities when DPL is negative or only positive by red blood cell count.(42, 15, 16) For this reason, some organizational guidelines utilize diagnostic peritoneal tap as a means to further evaluate intra-abdominal injury rather than surgical exploration. Unless, 5–0 ml of gross blood is identified on diagnostic peritoneal tap, the decision to perform laparotomy should be made after additional studies are obtained.(35) Nevertheless, the CT scanner, although accurate, is not the place for an acutely unstable patient.

The case study patient was appropriately managed to evaluate for immediate causes of hypotension. Clinically, the patient's airway was secured, breath sounds identified bilaterally, and heart sounds auscultated without difficulty. The pelvis was identified as unstable and a pelvic binder placed to help tamponade potential bleeding. The long bone fracture was splinted in place to tamponade potential bleeding. Subsequently, FAST ruled against cardiac tamponade, but identified free fluid in the pelvis. Chest X-ray did not show signs of major thoracic injury or occult pneumothorax. Pelvis X-ray identified an "open book" pelvis fracture. Knowing that this type of pelvic fracture is associated with hemorrhage and may benefit from pelvic volume reduction, application of a pelvic binder was a beneficial strategy. The patient's response to resuscitative efforts allowed for additional diagnostic studies, such as CT scan. CT scan of the head did not identify an intracranial source of the patient's presenting confusion. This finding in combination with free fluid on FAST and an unstable pelvic fracture on X-ray identify hypotension secondary to hemorrhage as a cause of mental status changes. The patient's positive response to volume resuscitation and pelvic binding facilitated the use of CT scanning to evaluate the thorax, abdomen, pelvis, and bladder. In addition to the previously identified pelvic fractures, CT evaluation revealed a small area of active extravasation in the right pelvis and an extraperitoneal bladder rupture. There was no additional solid organ injury identified.

EXTERNAL FIXATION VERSUS ANGIOEMBOLIZATION

Hemodynamic instability secondary to pelvic hemorrhage is a complex challenge for the physician. A high suspicion of vascular injury and early identification pelvic hemorrhage is key in implementing a therapeutic strategy. Numerous methods exist to help obtain hemostatic control. It is known that pelvic hemorrhage can occur from exposed cancellous bone, iliac artery branches, and presacral veins that transverse the pelvis.(43, 13) Although numerous authors cite venous disruption as the major cause of pelvic bleeding, various institutional experiences have resulted in various algorithms to achieve hemostasis.(5, 44, 45)

Mechanical pelvic stabilization and angiographic embolization of arterial bleeding is the cornerstone to all of these protocols. The goal of mechanical pelvic stabilization is to decrease pelvic volume, realign bony surfaces, and tamponade retroperitoneal bleeding. Mechanical pelvic stabilization can be obtained via invasive external orthotic devices such as an external fixator (Ex-Fix) or C-clamp. Anterior fixation with an Ex-Fix has been shown to control venous bleeding in numerous clinical studies and laboratory models.(42, 46–48) Pins are placed in the anterior iliac spine bilaterally and the pelvis is reduced by attached crossbars. In contrast, posterior fixation can be obtained by attaching a C-clamp to the posterior ilium or greater trochanters.(5, 47, 49) Serious complications such as hematoma disruption, ilium perforation, and soft tissue infections have decreased enthusiasm for C-clamp use, while obstructing crossbars have limited Ex-Fix utilization in the pelvic fracture patient with additional abdominal injuries.(50)

Although both devices can be placed in the emergency department or operating room, it is estimated to take 30 or 60 minutes, respectively, in the best of hands.(51) Consequently, these invasive techniques have largely been replaced by noninvasive techniques of pelvic stabilization such as circumferential wrapping of a folded bed sheet or application of a pelvic binder.(52) These adjuncts are noninvasive, require less than 5 minutes for application, and may offer immediate benefit during primary examination and resuscitation. Likewise, these techniques do not require the involvement of a surgeon.(32) Nevertheless, pelvic reduction is generally accepted as a means to treat anterior–posterior compression factors, rather than other fracture patterns.(53)

Not all pelvic fracture patterns respond to initial attempts at bony stabilization. In 1972, Margolies et al. described angiographic identification and control of bleeding from the hypogastric artery in three patients with unstable pelvic fractures.(54) Panetta and Scalfani later showed transcatheter angioembolization as an effective means to control massive retroperitoneal hemorrhage from pelvic fractures.(55) Numerous authors have echoed the use of angioembolization as a means to control arterial hemorrhage and reduce blood transfusion requirements. (56–58) Importantly, this group showed decreased mortality in patients who undergo angioembolization within 1 h (14%) in comparison to those patients who receive angioembolization at 3 h (75%).(56)

Unfortunately, 26–46% of patients will have no bleeding identified on angiography.(56, 59, 11) This failure rate is reduced if a contrast blush is observed on CT scan.(60) Nevertheless, the decision to obtain a CT scan in an unstable patient can have disastrous results. In a similar fashion, the angiography suite is not designed to provide the same level of care as a trauma room, operating room, or ICU. Likewise, angiography can be a time-consuming procedure to perform and set up, even in the best-equipped institutions. Therefore, transportation of an unstable patient to the angiography room may not be feasible. Nevertheless, angioembolization has become the preferred method to control arterial pelvic hemorrhage.

Prediction of arterial bleeding based upon fracture pattern, clinical signs, and hemodynamic changes remains complex and resource dependent. Consequently, the timing of angiography is controversial and driven by various clinical guidelines that are institution specific.(14, 61) At best, it is rational to say that noninvasive external pelvic fixation can help hemostasis from venous sources, bony surfaces, and small arterial vessels during resuscitation. Once abdominal clearance has been obtained and the pelvis identified as the source of hemorrhage, the decision to proceed immediately to angiogram is based upon availability and should not be delayed. In the severely unstable patient or in situations where there is a delay in obtaining angioembolization, damage control pelvic packing may be helpful.(62, 63) Furthermore, this technique may be advised in patients undergoing laparotomy for associated abdominal hemorrhage. A modified clinical algorithm for management of unstable pelvic fractures is shown in Figure 17.1.

Biomechanically Unstable Pelvic Fracture

IV Access (central venous line if needed)
Resuscitation with 2L crystalloid then blood products
A/P Pelvis
A/P Chest
Non invasive Pelvic Orthotic Device (Binder, sheet)

Unstable Hemodynamics

FAST exam

Free Fluid   No Free Fluid

Laparatomy (DCS)
Pelvic Packing
External Fixator
Pelvic C clamp

Patient in Extremis

Yes   No

Extraperitoneal
Pelvic Packing
Damage Control

An giography
+/–C clamp

Angiography   **CT Scan**

Improved Hemodynamics

No   No

SICU

Stable Hemodynamics

FAST exam

Free Fluid   No Free Fluid

CT Scan

Blush on CT

Yes   No

Angiography
+
Address other injuries (?OR)

Address other injuries

SICU

Elective Pelvic Fixation

Consider repeat angiography or surgical bleeding control

Figure 17.1 Modified clinical algorithm for the initial management of unstable pelvic fractures (18, 20, 36, 82).

Although the case study patient had free fluid on FAST examination, her clinical response to intravenous resuscitation and a pelvic binder promoted the decision to obtain a CT scan. Active extravasation of contrast on CT alerted physicians to the need for angiography. Angioembolization safely stopped the bleeding. The absence of free fluid on FAST would identify the pelvis as the major source of bleeding and promotes the use of angiography prior to CT scanning. The lack of response to intravenous resuscitation and the presence of abdominal free fluid on FAST would promote the need for exploratory laparotomy to control intra-abdominal bleeding. Angiography of the pelvis would follow surgery. Pelvic packing may be used to control associated pelvic bleeding. This will be discussed below.

PELVIC PACKING AS DAMAGE CONTROL HEMOSTASIS

Although operative control seems like a rational approach to a patient with hemorrhage, direct surgical control of pelvic bleeding is generally not a good idea. A number of rationales support this strategy: (1) direct ligation of bleeding vessels in pelvic hematomas is technically difficult (64), (2) bilateral ligation of the hypogastric arteries does not effectively reduce arterial flow in the distal vessels (65), (3) laparotomy incisions increase pelvic volume by more than 15% (38), and (4) disruption of pelvic hematomas will reduce tamponade. Similarly, anecdotal reports of the use of sterile thumb tacks, bone wax, electrocautery, and various hemostatic agents have not proven to be successful.(63, 66)

Current algorithms in most trauma centers for management of unstable patients with pelvic hemorrhage generally consist of aggressive resuscitation, mechanical pelvic stabilization, and angioembolization.(67) However, specific modalities and resources are institution specific. If the necessary resources are not immediately available, time to angioembolization or pelvic fixation may prolong hemodynamic instability, increasing morbidity and mortality. Moreover, the transport of a hemodynamically compromised patient to areas in the hospital with limited resuscitative capabilities may not be wise.

Pelvic packing was described in the literature as early as 1926. (68, 69) Pelvic packing as operative intervention for pelvic fractures was first described by Hawkins et al. in 1970. (70) In the original report, the author's discouraged bilateral hypogastric artery ligation and yet suggested a preoperative transfusion of 20 units of red cells as indication for the technique.(70) More recently, many European studies have supported extraperitoneal pelvic packing in patients with persistent hemorrhagic shock.(44, 62, 71–73) Extraperitoneal pelvic packing has gained enthusiasm as a salvage technique serving as a bridge to angiographic embolization.(67)

Utilizing preperitoneal packing as part of this treatment strategy should be considered a form of damage control. This may occur at the time of exploratory laparotomy for intra-abdominal hemorrhage or as an isolated operative procedure. When done in conjunction with a laparotomy, it is important to leave the pelvic peritoneum intact. The pelvis should be packed utilizing a separate incision. The intact pelvic peritoneum serves as the surface against which to pack hemostatic material. Other operative techniques may also be used in conjunction with extraperitoneal pelvic packing. Percutaneous sacral–iliac fixation screws and limited anterior pelvic fixation may also prove valuable in the unstable patient with multiple intraperitoneal and retroperitoneal injuries.(74)

Numerous European studies have supported early pelvic fixation with an external fixator or a C-clamp and pelvic packing in patients with persistent pelvic hemorrhage.(1, 11, 71, 75–77) Most recently, Clothren et al. published a study utilizing very early pelvic packing. Their technique involved exploration via a lower midline incision. The extraperitoneal space was packed using laparotomy pads on each side of the bladder and into the true pelvis below the pelvic brim.(67) The midline fascia can also be closed to help tamponade bleeding.(63) Although limited by study size, mortality from pelvic hemorrhage was significantly lower (25%) than other previously reported techniques (40%).(12, 20, 67, 78)

At present, there are no randomized trials available to evaluate the utility of angioembolization versus pelvic packing. However, it is expert opinion that angioembolization is the optimal means to control pelvic bleeding.(56) Conversely, pelvic packing as a form of damage control appears to be an advantageous salvage strategy, particularly when used as a temporary bridge to additional therapies such as angioembolization. In addition, extraperitoneal pelvic packing may serve as the only means to control pelvic hemorrhage in rural settings or other austere environments where resources are limited. Future studies will be needed to evaluate appropriate indications, comparative benefits, and outcomes from this technique.

> The case study patient did not require damage control surgery to control pelvic hemorrhage.

COMPLICATIONS FROM PELVIC FRACTURES

Associated injuries are common in patients with pelvic fractures. Logically, the high amount of energy needed to fracture a pelvis is also distributed throughout the body resulting in additional injury. Various studies have correlated specific associated injuries to the type of pelvic fracture.(16, 17, 79) These include intra-abdominal injuries such as liver, bladder, and urethra, as well as brain injuries being associated with AP compression fractures. (22, 27) Similarly, specific mechanisms of injury have a higher incidence of associated severe injuries.(80) For example, motor vehicle crashes are less associated with severe pelvic fractures and concomitant intra-abdominal injuries.(12) Likewise, injuries to the urethra, bladder, and peripheral nerves are directly related to fractures of the bony pelvis. Extraperitoneal bladder rupture occurs 80% of the time when associated with a pelvic fracture.(34) Urethral injury occurs three times as often in males than females. (33, 81, 82) Injury to the sacral plexus or nerve roots may result in an immediate or delayed complication. Nerve injury may persist after pelvic fixation and correlates with sexual dysfunction. (83, 84) The most studied complication associated with pelvic fractures is pelvic hemorrhage. Bleeding may occur in as many as 70% of patients with pelvic fracture.(4, 19, 17) Venous bleeding is usually from the rich venous plexus in the posterior pelvis. Arterial bleeding usually results from direct injury to vessels close to the bony injury. These are usually braches of the internal iliac artery. Posterior fractures may injure the superior gluteal artery, while anterior fractures may injure the internal pudendal artery.

It is important to assess for abdominal compartment syndrome or abdominal hypertension in this setting. Resultant hematomas are at risk for abscess formation and infection. Associated bowel or bladder injuries may also result in infection. Similarly, the need for increased blood product transfusions and intravenous resuscitation increases a patient's risk for pulmonary complications such as acute respiratory distress syndrome.(85) Associated wounds from operative intervention are at risk for wound infection. Pelvic fractures are associated with a 50% incidence of deep venous thrombosis.(86) Although hard to visualize with ultrasound, it is estimated that many significant pulmonary emboli originate in the pelvic veins. MRA and CT are useful in

evaluating these emboli. DVT prophylaxis is an important part of the treatment of pelvic fractures. Long-term complications include pain, osteoarthritis, malunion, nonunion, and difficulty with mobilization.

> The case study patient encountered two immediate complications from pelvic fracture. She sustained pelvic hemorrhage controlled by a pelvic binder and angioembolization, and a extraperitoneal bladder rupture treated with urinary catheterization for 2 weeks.

OUTCOMES

Pelvic fractures with associated pelvic hemorrhage are severe injuries with high morbidity and mortality. Such injuries are a result of significant forces and rarely occur in isolation. Numerous algorithms and techniques have been introduced to improve initial stabilization and treatment to improve survival. Although universal guidelines are not fully accepted, numerous groups have reported improvement in mortality rates via a standardized protocol of early diagnosis, resuscitation, and aggressive treatment of associated injuries.(61) Conversely, long-term outcome and disability from pelvic fractures have been of secondary importance. Limitations to clinical outcomes research for pelvic trauma are numerous.

The high association of pelvic fractures with other devastating injuries clearly confounds data and blurs a patient's view of long-term sequelae. Moreover, it is difficult to develop a functional outcome scale to reflect pelvic fracture impairment because disability from pelvic fractures may affect nonspecific daily activities such as sitting and standing.(87) Similarly, the factors related to poor outcome can be controversial. For example, potential litigation and secondary gain may exert influence on a patient's response. Finally, outcome studies need to be performed over a specific period of time to provide valuable results. Hence, an extensive recovery period may influence results of shorter time intervals, and longer study periods may result in loss of patient follow-up. Despite these limitations, a few groups have started to look at long-term disability and outcome associated with pelvic trauma. Using the Sickness Impact Profile (SIP), Gruen et al. showed that 77% of patients with unstable pelvic fracture patients treated with ORIF reported mild disability, a 1-year post-injury.(88) Despite the magnitude of injury, approximately 60% of these patients returned to work full time and an additional 14% returned to work with a job modification.

Using the Short Form 36 General Health Survey (SF-36), Miranda et al. echoed these results with 80% of patients returning to their previous occupation after treatment by pelvic external fixator.(89) The majority of these patients reported their worst sequelae as pain. Results of the SF-36 distributed to patients with open pelvic fractures suggest that a distinct chronic disability to these patients described a decreased daily functioning.(23) Moreover, associated neurologic injury and/or brain injury is associated with worse functional outcome on SF-36 and the Iowa Pelvic Score for pelvic fractures patients treated with either ORIF or external fixation.(87) Although minimal in number,

some studies have correlated posterior displacement of greater than 1 cm after open internal fixation with worse long-term pain and disability.(90, 91) Moreover, Korovessis et al. showed better functional outcomes in patients without associated injuries.(92) From these reports, it is clear that controversy remains regarding factors that influence long-term outcome. It is apparent that these controversies are as many as those that influence initial treatment protocols. Nevertheless, it is fair to say that pelvic fractures are severe injuries in isolation. The presence of pelvic hemorrhage and associated intra-abdominal injuries only complicates decision making for initial and long-term intervention. Prospective studies are needed on all fronts to quantify morbidity, mortality, and outcome.

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Table 1. Evidentiary table of recommendations as indicated on the algorithm presented in figure 1. Recommendations and quality of evidence strength grades are made following American College of Chest Physician guidelines (Gordon, G; Gutterman, D, et al. Chest 2006; 129: 174 – 181.)

Recommendation	Evidence Grade
1. Once life threatening causes of hypotension are evaluated and managed, the pelvis should be evaluated clinically and by plain X –ray. A FAST Exam to evaluate for free fluid is recommended to evaluate non-pelvic sources of bleeding.	
a. Boulanger BR, Kearney PA, Brenneman FD, Tsuei B, Ochoa J. Utilization of FAST (Focused Assessment with Sonography for Trauma) in 1999: results of a survey of North American trauma centers. *Am Surg* 2000; 66: 1049–55.	1C
b. Rozycki GS, Ballard R, Feliciano DV, Schmidt JA, Pennington SD. Surgeon performed ultrasound for the assessment of truncal injuries. Ann Surg 1998; 228: 557–67.	1B
c. Ballard RB, Rozycki GS, Newman PG et al. An algorithm to reduce the incidence of false-negative FAST examinations in patients at high risk for occult injury. J Am Coll Surg 1999; 189: 145–51.	1B
d. Chiu WC, Cushing BM, Rodriguez A et al. Abdominal injuries without hemoperitoneum: a potential limitation of focused abdominal sonography for trauma (FAST). J Trauma 1997; 42: 617–25.	1B
e. Hubbard SG, Bivins BA, Sachatello CR, Griffen W. Diagnostic errors with peritoneal lavage in patients with pelvic fractures. Arch Surg 1979; 114: 843–6.	1C
f. Evers BM, Cryer HM, Miller FB. Pelvic fracture hemorrhage. Priorities in management. Arch Surg 1989; 124: 422–4.	1B
g. DiGiacomo JC, Bonadies JC, Diebel L et al. EAST Trauma Practice Guidelines. Available at: http://www .east. org/tpg.html/. Accessed July 7, 2008.	1B
2. Hemodynamically stable patients with pelvic fractures associated with or without free fluid on FAST evaluation should proceed to CT scan.	
a. Shanmuganathan K, Mirvis SE, Sover ER. Value of contrast enhanced CT in detecting active haemorrhage in patients with blunt abdominal or pelvic trauma. AJR Am J Roentgenol 1993; 161: 65–69.	1B
b. Balogh Z, Caldwell E, Heetveld M et al. Institutional practice guidelines on management of pelvic fracture-related hemodynamic instability: do they make a difference? J Trauma 2005; 58: 778–82.	1B
c. Biffl WL, Smith WR, Moore EE et al. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg 2001; 233: 843–50.	1B
3. Hemodynamically stable patients with pelvic fractures and evidence of a contrast blush on CT Scan should proceed to angiography and embolization.	
a. Shanmuganatha pelvic trauma. AJR Am J Roentgenol 1993; 161: 65–9.	1B
b. Balogh Z, Caldwell E, Heetveld M et al. Institutional practice guidelines on management of pelvic fracture-related hemodynamic instability: do they make a difference? J Trauma 2005; 58: 778–82.	1B
c. Biffl WL, Smith WR, Moore EE et al. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg 2001; 233: 843–50.	1B
4. Hemodynamically unstable patients with pelvic fractures who are not in *extremis* should proceed to angiography and be considered for external pelvic stabilization prior to CT scan.	
a. Wolinsky, PR .Assessment and management of pelvic fracture in the hemodynamically unstable patient. Orthop Clin North Am. 1997; 28: 321–9.	1C
b. Balogh Z, Caldwell E, Heetveld M et al. Institutional practice guidelines on management of pelvic fracture-related hemodynamic instability: do they make a difference? J Trauma 2005; 58: 778–82.	1B
c. Biffl WL, Smith WR, Moore EE et al. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg 2001; 233: 843–50.	1B
d. Croce MA, Magnotti LJ, Savage SA, Wood GW 2nd, Fabian TC. Emergent pelvic fixation in patients with exsanguinating pelvic fractures. J Am Coll Surg 2007; 204: 935–9.	1B
Anterior Approach	
e. Grimm MR, Vrahas MS, Thomas KA. Pressure-volume characteristics of the intact and disrupted pelvic retroperitoneum. J Trauma 1998; 44: 454–59.	1B
f. Evers BM, Cryer HM, Miller FB. Pelvic fracture hemorrhage. Priorities in management. Arch Surg 1989; 124: 422–4.	1B

g. Tornetta P, Richard M. Emergent management of APC 2 pelvic ring injuries with an anteriorly placed C-clamp. Orthopaedic Trauma Association 19th Annual Meeting, Salt Lake City, Utah, USA; October 9–11, 2003.	1B
h. Waikakul S, Harnroonroj T, Vanadurongwan V. Immediate stabilization of unstable pelvic fractures vs delayed stabilization. J Med Assoc Thai 1999; 82: 637–42.	1B
i. Pohlemann T, Culemann U, Gansslen A, Tscherne H. Severe pelvic injury with pelvic mass hemorrhage: determining severity of hemorrhage and clinical experience with emergency stabilization. Unfallchirurg 1996; 99: 734–43 (in German).	1C
Posterior approach	
j. Archdeacon MT, Hiratzka J. The trochanteric C-clamp for provisional pelvic stability. J Orthop Trauma 2006; 20: 47–51.	1B
k. Ertel W, Keel M, Eid K, Platz A, Trentz O. Control of severe hemorrhage using C-clamp and pelvic packing in multiply injured patients with pelvic ring disruption. J Orthop Trauma 2001; 15: 468–74.	1B
l. Tornetta P, Richard M. Emergent management of APC 2 pelvic ring injuries with an anteriorly placed C-clamp. Orthopaedic Trauma Association 19th Annual Meeting, Salt Lake City, Utah, USA; October 9–11, 2003.	1B
m. Pohlemann T, Culemann U, Tosounidis G et al. [Application of the pelvic C-clamp]. Unfallchirurg 2004; 107: 1185–91.	1C
5. Hemodynamically unstable patients with pelvic fractures who are in *extremis* should be considered for extraperitoneal pelvic packing or damage control pelvic packing as a bridge to angiography and embolization.	
a. Totterman A, Madsen JE, Skaga NO et al. Extraperitoneal pelvic packing: a salvage procedure to control massive traumatic pelvic hemorrhage. J Trauma 2007; 62: 843–52.	1B
b. Pohlemann T, Bosch U, Gansslen A et al. The Hanover experience in management of pelvic fractures. Clin Orthop Relat Res 1994; 305: 69–80.	1B
c. Pohlemann T, Culemann U, Gansslen A, Tscherne H. Severe pelvic injury with pelvic mass hemorrhage: determining severity of hemorrhage and clinical experience with emergency stabilization. Unfallchirurg 1996; 99: 734–43 (in German).	1C
d. Pohlemann T, Gansslen A, Hufner T, Tscherne H. Extraperitoneal packing at laparotomy. Abstract OTA-AAST Annual Meeting, 2000.	1B
e. Gansslen A, Giannoudis P, Pape HC. Hemorrhage in pelvic fracture: who needs angiography? Curr Opin Crit Care 2003; 9: 515–23.	1C
f. Cothren CC, Osborn PM, Moore EE et al. Preperitoneal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. J Trauma 2007; 62: 834–42.	1B
e. Smith WR, Moore EE, Osborne P et al. Retroperitoneal packing as a resuscitation technique for hemodynamically unstable pelvic fractures: report of two cases and description of technique. J Trauma 2005; 59: 1510–4.	1C
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18 The mangled extremity
Samuel C Schecter, Scott L Hansen, and William P Schecter

A 56-year-old intoxicated female is transferred to the emergency room from an outside hospital 2 h after she was hit by a car at low speed. The patient was thrown to the ground, and the right front wheel of the car ran over her right lower extremity. The patient experienced no loss of consciousness. She is awake and alert, has no respiratory difficulties, the blood pressure is 126/82, and the heart rate is 78 bpm. On secondary survey, there is a swollen dislocated right knee and an obvious distal tibia fracture with bone protruding through a 20 cm × 10 cm skin defect (Figure 18.1). The right lower extremity is pulseless, pale, and insensate. A Betadine®-soaked dressing is placed over the open fracture, and the right lower extremity is immobilized. One gram of cephazolin is administered intravenously.

After completion of the primary and secondary surveys, the patient is transported immediately to the operating room (OR). The vital signs remain stable. After induction of anesthesia, the fracture is reduced, but the right foot remains pale and pulseless by palpation and on Doppler examination. An on-table angiogram is performed after cannulation of the right femoral artery. No flow is demonstrated distal to the right popliteal artery.

After sterile preparation and draping of the abdomen and both lower extremities, the right popliteal artery is explored. A large hematoma is present in the popliteal fossa. A near transaction of the popliteal artery with extensive intimal disruption and a severe injury to the popliteal vein are identified. After obtaining proximal and distal control, the vessels are debrided back to normal tissue. A #4 pediatric endotracheal tube, cut to length, is inserted as a temporary stent, bridging the gap in both the popliteal artery and vein. The stent is fixed in place with heavy silk ligatures. Capillary refill is now present in the toes, and a right posterior tibial pulse is present on Doppler examination.

Attention is then turned to the bone and soft-tissue injuries. Anteroposterior and lateral X-rays of the right tibia and fibula including the knee and ankle are reviewed, as well as the right femur films which include the hip and knee. Comminuted fractures of the right tibia and fibula are present. The skin laceration is extended and debrided. There is extensive crush injury of the tibialis anterior muscle and the gastrocnemius muscle. The soleus muscle is stripped for a distance of 6 cm from its attachment to the tibia in the region of the fracture. The knee joint is injected with methylene blue dye. There is no extravasation of methylene blue, indicating that the joint has not been disrupted.

All nonviable skin and muscle are debrided to bleeding tissue. The viability of large areas of muscle is questionable. These areas are not debrided. Reinspection of this area in 24–48 h in the OR is planned. The wound is vigorously irrigated with a high-pressure jet irrigation system until all of the dirt and gravel are removed. The fractures are stabilized with an external fixation system. Fasciotomy of the anterior and lateral compartments and the superficial and deep posterior compartments is performed.

The patient remains hemodynamically stable after transfusion of 3 units of packed cells. Her temperature and pH are normal. The injuries to the popliteal artery and vein are reassessed. Both shunts remain in good position with good flow. Vascular reconstruction is performed at this time as the patient remains hemodynamically stable. Autogenous saphenous vein grafts harvested from the contralateral (left) leg are used in preference to synthetic grafts because the injury is located in the popliteal fossa adjacent to the Grade IIIc tibia fracture. The popliteal artery is repaired first followed by the popliteal vein. The vein grafts are covered with local soft tissue. A subatmospheric sponge dressing is applied to the wound, and the patient is taken to the ICU for monitoring.

Figure 18.1 Tibia fracture with unstable soft-tissue coverage.

The patient returned to the OR on four occasions over the next 10 days for repeated debridement and irrigation. There was diminished but present sensation in the right foot. On the10th day following injury, the patient underwent a rectus abdominis muscle free flap to cover the exposed tibia. A split-thickness skin graft was then used to cover the muscle (Figure 18.2).

Postoperatively, the patient was observed closely for any flap compromise necessitating an emergent return to the OR. The patient was discharged to a skilled nursing facility for physical therapy on postop day #10 following the free flap. Weight bearing was instituted upon stable bone healing.

THE MANGLED EXTREMITY: GENERAL OVERVIEW

The mangled extremity is a common problem following blunt- and high-velocity penetrating trauma. Combined neurovascular, skeletal, and soft-tissue injuries (1) create a potential limb-loss situation that challenges the reconstructive skills of the surgical team. Treatment based on a set of prioritized management principles offers the best chance for functional recovery.

Demographics and Epidemiology

Most severe injuries to the lower extremities in civilian practice are the result of motor vehicle accidents.(2) Approximately one third of patients injured in motorcycle accidents have at least one open fracture.(3) Train accidents are a particular risk. In a recent series, 45 (56%) of 80 surviving train accident victims had 57 extremity fractures and 30 (38%) patients required 40 amputations.(4) Complex extremity injuries also occur frequently following terrorist bomb explosions (5) and injury caused by both blast effect and high-velocity penetrating trauma in combat situations.(6)

What Are the Morbidity and Mortality Rates Associated with Mangled Lower Extremities?
Failed attempts at limb salvage are associated with an increased risk of death.(7) However, there is little data in the literature that quantify the direct relationship between mortality and lower

extremity injury. Depending on the mechanism of injury, the mangled extremity may be associated with multiple other life-threatening injuries. Some patients with mangled extremities exsanguinate in the field prior to the arrival of help. However, local pressure plus proximal tourniquet control if necessary combined with fluid resuscitation should prevent death due to exsanguination in patients who arrive alive at the hospital.

Occasionally a patient may be trapped under a collapsed structure with a crush injury to the lower extremity. Extrication may take many hours. In such a situation, hyperkalemia is a serious risk. A hyperkalemic cardiac arrest can occur after reperfusion (8) Acute renal failure due to myoglobinuria is another significant risk after crush injury. Aggressive fluid therapy with isotonic crystalloid is important. Traditionally, urine alkalinization with sodium bicarbonate and diuresis with mannitol were recommended to decrease the risk of myoglobin deposition in the renal tubules. (9) However, the efficacy of urine alkalinization and diuresis has recently been challenged.(10)

Other potential causes of death are necrotizing soft-tissue infections and the adult respiratory distress syndrome caused by fat emboli.(11, 12) There is a 69% incidence of deep venous thrombosis associated with lower extremity injury and a significant risk of pulmonary thromboembolism if prophylactic anticoagulation is not employed.(13)

Should the Patient with the Mangled Extremity Be Taken Directly to the OR or Should More Images Be Obtained to Better Characterize the Injury?
Trauma patients pass through a diagnostic and therapeutic triage cascade at various stations throughout the hospital. The decision regarding the next destination of care for a patient with a mangled extremity is influenced by multiple factors: the nature of the injury, the skills of the clinicians present, the duration of warm ischemia, the availability of an OR, and the equipment available. Patients with uncontrolled hemorrhage, due to either the mangled extremity itself or the other associated injuries requiring surgical intervention, must be transported directly to the OR. The patient presented herein was hemodynamically stable but already had a 2-h period of warm ischemia. She was transported directly to the OR rather than to
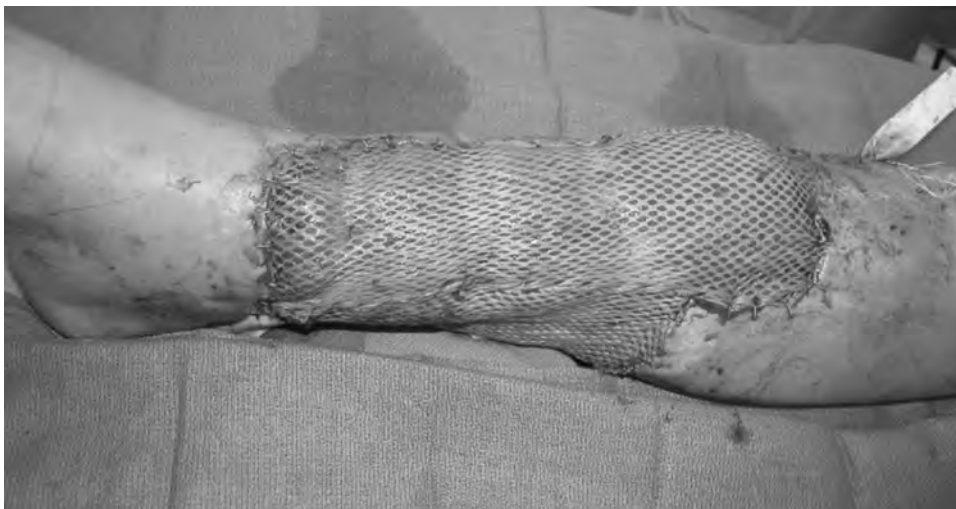
Figure 18.2 Stable coverage of exposed tibia fracture with a rectus abdominis muscle flap with split-thickness skin graft.

interventional radiology to perform a CT angiogram or a formal angiogram for several reasons: (1) a 64-slice CT scanner was not available to provide rapid accurate vascular images; (2) prolongation of the preoperative warm ischemia time is to be avoided; and (3) an on-table angiogram readily and accurately shows the nature and location of the vascular injury and permits immediate intervention.

As a general principle, hemodynamically stable patients with a short period of ischemia should have a rapid preoperative CT angiogram to define the nature of the vascular as well as the skeletal injury.(14) However, on-table angiography can answer most clinical questions (15) and is preferred by many surgeons. Once reperfusion and fasciotomy are achieved, additional images to plan skeletal stabilization may be obtained in the OR.

General Approach to Reconstruction of the Lower Extremity
The lower extremity is composed of a skin envelope containing fascia, muscle–tendon units, arteries, veins, nerves, and bone. The primary goal of reconstruction is achievement of a stable bone fixation covered by well-vascularized soft tissue. All secondary reconstruction and rehabilitation goals are dependent on achievement of the primary goal. The ultimate goal is limb salvage via complex reconstructive surgery so that the patient can walk and resume his or her role in society.

The priorities of evaluation and reconstruction are

1. assessment and restoration of arterial perfusion
2. restoration of venous drainage
3. prevention or treatment of compartment syndrome
4. debridement of nonviable or infected soft tissue
5. assessment and treatment of nerve injury
6. skeletal stabilization
7. repair of muscle–tendon units
8. coverage of exposed bone with well-vascularized soft tissue and skin.

A multidisciplinary approach involving trauma and acute care surgeons, orthopedists, and reconstructive surgeons is frequently necessary depending on the complexity of the injury and the skill set of the responsible surgeon.

Amputation or Reconstruction?
The decision to perform primary amputation versus reconstruction of the mangled extremity is often difficult. Two basic considerations should guide the surgeon in making this complex decision: (1) What are the systemic consequences of reconstructing the severely injured leg? and (2) What is the probability that reconstruction will achieve the goal of a pain-free independently walking patient who will return to his or her role in society? The question of amputation is most often raised in patients with Grade IIIc tibia fractures (Table 18.1). Severe crush injury of the leg with a warm ischemia time > 6 h associated with anatomic loss of the tibial nerve is an absolute indication for amputation. Relative indications for amputation include severe associated injuries, crush injury to the ipsilateral foot, and the requirement for prolonged complex reconstruction in a patient with extensive comorbidities.(16) If primary amputation is required, occasionally

skin grafts can be harvested from the amputated limb for use in reconstruction. Rarely, the sole of the foot can be replanted with microvascular techniques to cover a below-knee amputation stump to maintain length. Every effort should be made to preserve the knee as the function and energy requirements of a below knee amputation are superior to an above-knee amputation (17, 18)

Table 18.1 Gussilo–Anderson Classification of Open Fractures. (20, 21)

Type	Soft Tissue Wound	Associated factors
I	< 1 cm	
II	1–10 cm	
III A	> 10 cm coverage possible	Segmental fractures, heavy contamination, high-velocity GSW
III B	10 cm requiring soft tissue coverage procedure	Periosteal stripping
III C	Same as III B	Vascular injury requiring repair

Figure 18.3a Traumatic amputation of the left lower extremity.

Figure 18.3b Exposed 11 cm of the proximal tibia with unstable soft-tissue coverage.
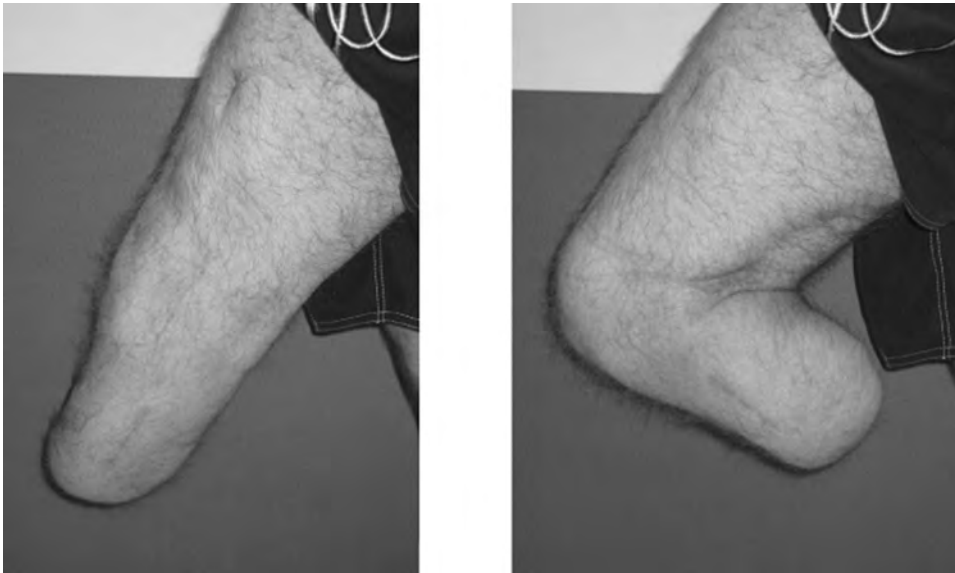
Figure 18.3c Salvage of a below-the-knee amputation with a microvascular rectus abdominis muscle to cover the exposed proximal tibia with excellent functional recovery.

(Figure 18.3a, b, and c). Knee preservation should be considered in consultation with a reconstructive surgeon even if local tissue for coverage is not available. Delayed coverage with a muscle or musculocutaneous flap may result in a functional below-knee amputation.(19)

MANGLED EXTREMITY SCORING SYSTEMS

A number of scoring systems have been developed since 1985 to provide an objective assessment of the mangled extremity. The hope was that a numerical score would provide an objective basis for the decision to proceed with amputation rather than reconstruction. All of the scores used to evaluate the extent of the injury are based on the Gustilo–Anderson system of classifying open fractures (20, 21) (Table 18.1).

The Mangled Extremity Severity Index (MESI)

This score introduced in 1985 assigns points for injury severity score, shock, age, hemodynamic status, pre-existing disease, and severity of injury to the skin, muscle, bone, nerve, and vascular structures. The authors asserted that a MESI score > 20 was predictive of amputation.(1)

The Predictive Salvage Index (PSI)

This score introduced in 1987 attempts to predict the need for amputation in patients with combined orthopedic and vascular injuries. It assigns a weighted score based on warm ischemia time, time to treatment, and the degree of bone, muscle, and skin injury.(22)

The Mangled Extremity Score (MESS)

MESS is the most widely referenced score. This score was proposed in 1990 and evaluates four parameters: skeletal injury, vascular injury, shock, and age. The score was devised after a retrospective review of 25 patients and validated in a prospective review of an additional 26 limbs. The developers of this scoring system concluded that a MESS score ≥ 7 was 100% predictive of the need for amputation (23) (Table 18.2).

Nerve Injury, Ischemia, Soft-Tissue Injury, Skeletal Injury, Shock, and Age of Patient Score (NISSSA)

NISSSA is similar to MESS except that it adds a nerve injury score to the other MESS parameters. The proponents of NISSSA felt that loss of plantar sensation was most predictive of poor outcome and therefore suggested this scoring system to be more accurate than the MESS. Indeed, NISSSA had higher sensitivity (81.8% vs. 63.6%) and specificity (92.3 vs. 69.2%) compared to the MESS in predicting amputation.(24)

Limb Salvage Index (LSI)

This score was introduced in 1991 as a tool to assist in the treatment of patients with severe limb injury associated with vascular injury. The authors studied 7 parameters (arterial inflow, nerve function, fractures, skin integrity, muscle viability, deep venous injury, and warm ischemia time) in 26 patients with pulse deficits requiring revascularization. In these patients, amputation rate was 100% with an LSI score > 6.(25)

Hannover Fracture Scale (HFS)

The HFS was introduced in 1993 (26) and modified in 1997.(27) The authors evaluated shock, warm ischemia time, fractures, skin integrity, nerve injury, and degree of contamination. They concluded that the HFS was both highly sensitive and specific for prediction of amputation.

Do the Mangled Extremity Scoring Systems Accurately Predict the Risk of Amputation?

Six scoring systems were developed in a relatively short period of time to assist the surgeon in the evaluation of the mangled extremity and predict the risk of amputation. Are these systems really efficacious? Two retrospective studies compared the utility of the MESS, LSI, and PSI.(28, 29) Both studies concluded that there was little to no correlation between the score and the outcome suggesting no predictive utility. Bosse et al. prospectively studied 556 high-energy lower extremity injuries.(30) These

Table 18.2 Mangled Extremity Severity Score.(23)

Variables	Points
Skeletal/Soft Tissue Injury	
Low energy	1
Medium energy	2
High energy	3
Very high energy (gross decontamination)	4
Limb Ischemia*	
Reduced or absent pulse, normal perfusion	1
Pulseless, paresthesias, decreased capillary refill	2
Cool, paralyzed, insensate	3
Shock	
BP always > 90	0
Transient hypotension	1
Persistent hypotension	2
Age	
< 30 years	0
30–50 years	1
> 50 years	2

* Score doubled for ischemia time > 6 h

authors prospectively evaluated the MESS, LSI, PSI, NISSSA, and the HFS-97. Unfortunately, the study did not validate any of the scoring systems. Although low scores were predictive of limb salvage, the converse was not true. The authors concluded that lower extremity injury severity scores should be used with caution in the decision to amputate. At the present time, there is no independent evidence to validate the conclusions of the authors of the various scoring systems regarding the clinical utility of these scores. The decision to proceed with amputation at the present time must be based mainly on the mature clinical judgment of the attending surgeons taking into consideration the variables previously discussed.

Should the Fracture or the Vessels Be Fixed First?
The decision whether to repair the bone or the vessel first is based on several factors including the duration of ischemia (warm ischemic time), presence of hard signs of ischemia, and skeletal stability. As a general principle, restoration of vascular perfusion should precede bone stabilization when the warm ischemic time is long, hard signs of ischemia are present, and when the fracture is stable and requires minimal manipulation when reduced and repaired. In contrast, when the ischemic time is short, the leg distal to the injury is perfused, and much manipulation is required to repair an unstable fracture, fixing the bone should be prioritized. In the case presented above, the 2-h period of warm ischemia preceding the patient's arrival to the hospital mandated reconstitution of distal flow first.

What Are the Options for the Surgical Exposure of the Popliteal Vessels?
The popliteal artery is the continuation of the superficial femoral artery extending from the distal adductor canal of Hunter to the popliteus muscle of the posterior knee. The popliteal artery itself is divided into three anatomical sections: suprageniculate, infrageniculate, and midpopliteal. Surgical exposure of the popliteal

vessels may be achieved through five different approaches based on the level of the popliteal vessel injury.(31) A medial approach to the popliteal vessels permits exploration in the supine position, exposure of the entire popliteal artery and allows the surgeon the greatest range of surgical options for revascularization in the trauma patient.(31)

What Are the Indications for Temporary Vascular Shunts?
A definitive vascular repair should be avoided in the presence of cardiovascular instability and/or adverse local wound conditions.(32) Hemodynamic instability, coagulopathy, acidosis, and hypothermia are all contraindications to definitive repair. Skeletal instability, gross contamination or major loss of soft-tissue coverage is a relative contraindication to definitive repair. The skill set of the surgeon and the available equipment may also affect the decision regarding primary vascular repair. Inexperienced vascular surgeons or surgeons working in austere environments should consider temporary vascular shunts to restore limb perfusion.

A variety of commercial vascular shunts are available. However, any plastic tube irrigated with heparin saline can function as a temporary shunt. Intravenous tubing, tubes in closed system suction sets, pediatric endotracheal tubes or even small chest tubes cut to size may be used, depending on the size of the injured vessel. The shunt should be secured in place with heavy ligatures. The vessel should be debrided, thrombectomized distally with a Fogarty catheter, and irrigated with heparin saline solution prior to shunt insertion. Shunt patency should be monitored by direct observation or Doppler examination of the distal pulses. Definitive vascular repair is appropriate after achievement of cardiovascular stability and improvement in local wound conditions. Intravascular shunts have been left in place for up to 10 days (33) prior to definitive repair. However, definitive vascular reconstruction should be performed as soon as the patient has stabilized.

How Should the Artery Be Repaired?
When possible, the popliteal artery should be repaired primarily. However, mangled extremities are often associated with injury to a long segment of the artery. In this situation, primary anastomosis without undue tension is usually not possible despite mobilization of the proximal and distal segments of the vessel.

An interposition graft is usually the best option if primary repair is impossible. Polyflourotetraethylene (PTFE) grafts are excellent conduits for injuries above the knee and have excellent patency rates.(34) Repair with PTFE grafts is less time consuming compared with vein grafts, which could be critical in patients who are unstable, have multiple other injuries, and have a long period of ischemia. There is no randomized prospective trial comparing PTFE grafts and reverse saphenous vein interposition grafts for vascular injury in the popliteal fossa. A reverse saphenous vein graft harvested from the contralateral leg is a reasonable first choice in this situation. The role of cryo-preserved superficial femoral vein and superficial femoral artery as conduits for definitive repair of these injuries has not been defined. Extra-anatomic bypass of a severely injured contaminated area for definitive vascular

reconstruction can be considered in selected cases.(35) Extra-anatomic bypass has the virtue of placing the conduit through normal well-vascularized soft tissue. However, the procedure is more complicated and usually does not result in direct in-line flow.

Should the Vein Be Repaired?

There are a number of theoretical considerations favoring venous repair. The success rate of arterial repair is enhanced in the presence of adequate venous drainage. The probability of postoperative edema and the postphlebitic syndrome is decreased in the presence of good venous drainage. Even transient venous drainage may allow time for the development of collateral venous and lymphatic drainage decreasing the risk and severity of chronic leg swelling.(36) However, permanent sequelae of venous ligation are rare in civilian practice.(36)

In a review of 86 lower extremity venous injuries, the authors concluded that the short-term patency rates were 77% after primary repair and 72% after complex repair. There was a lower incidence of venous hypertension after vein repair and improved arterial flow and limb salvage. Eighteen venous injuries were treated initially with intraluminal shunts.(37) Repair of venous injuries proximal to and including the popliteal vein is reasonable. Venous ligation to preserve life is acceptable. Use of a temporary intraluminal shunt is effective. If a complex venous repair is required, a saphenous vein interposition graft (38) or a ringed PTFE graft (37) is a good option. There are no data comparing venous autografts with PTFE conduits.

Should the Artery or the Vein Be Repaired First?

Unfortunately there are neither level 1 data nor clinical consensus in the literature to guide the decision regarding the priority of venous verses arterial repair. Kuralay et al., in a study of 130 patients with lower extremity venous injuries, stated that they repaired the vein first in patients with combined arterial and venous injuries in the femoral and popliteal regions.(39) Huynh et al. stated that "when judged necessary …. venous return was restored before the arterial repair".(40) However, the specific indications for granting priority to venous repair were not discussed. Certainly the presence and duration of critical limb ischemia as well as the complexity of the venous and arterial injuries will affect the decision. Our general approach is repair of the artery prior to the vein in patients with a true mangled extremity. We make every effort to repair venous injuries at or above the popliteal fossa but do not repair venous injuries distal to the popliteal fossa. We have adopted this approach in order to minimize the period of ischemia. Surgeons advocating venous repair prior to arterial repair hope to reduce the risk of compartment syndrome.

What Are the Indications for Fasciotomy?

Surgeons should have a very low threshold for performing four-compartment fasciotomies in patients with mangled extremities.(41) In fact, patients with mangled extremities can only rarely be managed successfully without fasciotomy.

Although prophylactic fasciotomy is almost always indicated, if fasciotomy is not performed at the time of vascular repair, the patient must be closely observed with serial examinations and measurement of compartment pressures. Detection of compartment syndrome is particularly difficult in the patient with multiple injuries who is intubated and sedated receiving mechanical ventilation. A ΔP of ≤30 mm Hg between diastolic blood pressure and compartment pressure is an indication for urgent fasciotomy.(42)

There are four fascial compartments in the leg: the anterior, lateral, superficial posterior, and deep posterior compartments. A longitudinal incision on the proximal leg just lateral to the tibia provides direct access to the anterior compartment containing the tibialis anterior, extensor hallucis, and extensor digitorum muscles as well as the tibial artery and peroneal nerve. By retracting the incision laterally, access to the lateral compartment containing the peroneus longus and brevis muscles is obtained. Classically, the incision to access the superficial and deep posterior compartments is made on the proximal leg medial to the tibia. This incision gives easy access to the superficial posterior compartment. However, the soleus muscle takes origin from a long length of the tibia. The only way to decompress the deep posterior compartment through this incision is to take the soleus off of the tibia, a tedious and bloody procedure. Alternatively, the medial incision can be made distally. After decompression of the superficial posterior compartment containing the gastrocnemius muscle, the Achilles' tendon can be retracted medially exposing the plantar flexors of the deep posterior compartment wrapped in a fascial envelope which can be easily incised. Four compartment fasciotomy can also be preformed through a single lateral incision without fibulectomy as described by Rollins et al.(43)

Should Transected Nerves in the Mangled Lower Extremity Be Repaired?

High-energy injury with associated avulsion, disruption, or crush injury to the tibial nerve results in absence of plantar flexion and sensation. A primary amputation in this situation, particularly in the presence of a complex contaminated wound, should be strongly considered.(44) Neurorrhaphy in a mangled lower extremity is unlikely to result in significant functional recovery.(45) Rarely, the nerve is lacerated sharply which should be repaired with an operating microscope.

Is Replantation of a Lower Extremity Ever Indicated?

Level I data to guide the practicing surgeon as to whether replantation of the severed lower extremity should be performed do not exist. There are numerous case reports and case series which document the feasibility of lower extremity replantation.(46–50) Replantation of the severed lower extremity in select patient populations does meet with good functional clinical outcomes (Grades I and II) determined by the Chen criteria.(46) (Table 18.3)

Lower extremity reimplantation is possible because of advancements in microsurgical technique and the acceptance of Ilizarov's principle of bone distraction, which allows for elongation of the shortened extremity.(47–50)

A scoring system exists to aid in the decision process for replantation. Battiston et al., based on a retrospective analysis of 14 patients, modified the MESS to include the patient's age,
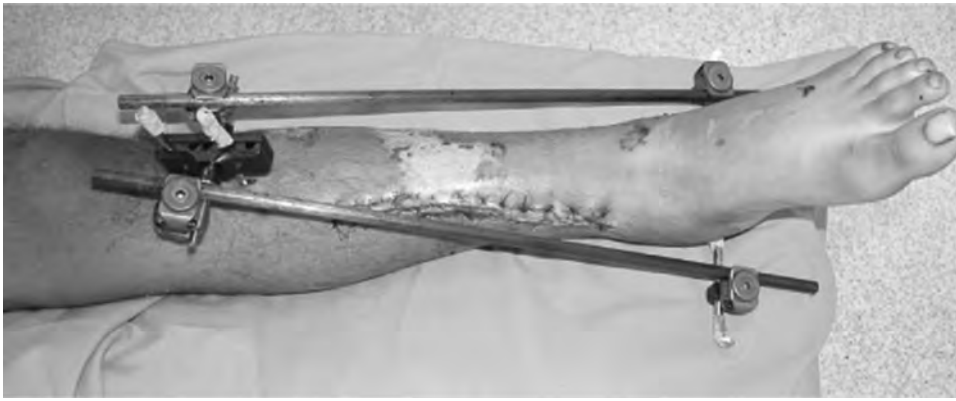
Figure 18.4a Uniplanar external fixator.

Figure 18.4b Multiplanar external fixator.

general conditions, ischemia time, and tissue defects (bone and soft tissue), which was able to predict outcome of replantation (48) (Table 18.4). Replantation should not be performed in patients with an amputated lower extremity and a score of 8 or above. Patients with a score of 6–7 have good viability of the replanted limb, but minimal function. An amputation may be the better option for these patients. Those patients with a score of ≤5 have a good functional outcome and should be considered for replantation of the amputated lower extremity.(48)

Despite these advances, lower extremity replantation is rarely indicated in adults.(51)

What Are the Options for Fracture Stabilization in the Mangled Lower Extremity?
Severe tibial shaft fractures often result in delayed union, lower extremity deformity, and stiff joints. Surgical stabilization permits rigid fixation, maintenance of correct alignment, and early motion of the knee and ankle joints. The anatomy of the specific fracture, the proximity of the fractures to the knee and ankle joint, and the condition of the overlying soft tissue will determine the type of fixation. As a general principle, intramedullary fixation of the tibia is the preferred method of surgical fixation.

Table 18.3 Chen Criteria for Extremity Function.(44)

Grade I	Return to work, normal gait and near normal knee function
Grade II	Light work, slight limp, good sensation, > 40% knee range of motion
Grade III	Useful in daily life, mild limb shortening, reduction of sensation and no ulceration
Grade IV	Use of crutches, loss of sole sensation, and trophic ulcers

(52) If intramedullary fixation is not possible, usually because of fracture location too far proximally or distally, external fixation is the best option. External fixators may be uniplanar or multiplanar (Figure 18.4a and b). Multiplanar-ringed external fixators maintain alignment, permit progressive increase in the load borne by the tibia, and allow access to complex wounds for debridement, treatment with antibiotic impregnated beads (53), and flap coverage.(54)

Do Antibiotic Impregnated Beads Lower the Risk of Osteomyelitis in the Mangled Extremity?
There are no randomized controlled human trials documenting that antibiotic beads placed directly into the bone prevent

Table 18.4 Limb Replantation Scoring System.(46)

Factors Affecting Successful Limb Replantation	Injury Severity Points				
	0	1	2	3	4
Age	< 30	30–50	> 50		
General conditions	Good health		Co-morbidities		Shock
Ischemia time	< 3 h warm or cold				> 6 h cold > 4 h warm
Tissue defects					
– Bone	Neat fracture, no contamination or bone loss	Complex fracture without much contamination or bone loss	Severe bone contamination and loss		Severe posterior tibial nerve injury
– Soft tissue	Good soft tissues	Skin Necrosis	Degloving injury	Large skin, muscle and tendon loss	Difficult reconstruction

osteomyelitis. Experiments in New Zealand white rabbits demonstrated a 66% reduction in the incidence of osteomyelitis after placement of antibiotic impregnated beads in experimental femur injuries.(55) The use of antibiotic beads aids healing of long-bone reconstruction.(56) A retrospective analysis of 49 cases of chronic osteomyelitis was performed in Hong Kong, which showed that the use of antibiotic bead implantation during surgery was effective in prevention of recurrence.(57) Currently, antibiotic beads are used in conjunction with aggressive debridement and staged wound care.

What Are the Options for Soft-Tissue Coverage of the Mangled Extremity?
Definitive soft-tissue coverage of the mangled extremity occurs after both the patient and wound bed are stabilized. Generally, the patient undergoes staged debridement of the wound over a 2-week time period. Between debridements, the wound is managed with a negative pressure dressing. The various defect components including bone, muscle, nerve, tendons, subcutaneous tissues, and skin must be carefully considered prior to reconstruction. The location of the defect also determines the type of reconstruction performed. Oftentimes in mangled extremity wounds, there is a paucity of locally available tissues to close the wound. In the lower extremity, the gastrocnemius and soleus muscles are often in the zone of injury and thus should not be used for reconstruction. Given this, microsurgical free-tissue transfer has become the mainstay of mangled extremity reconstruction. Although complicated, most large centers report 98% success rates with free-tissue transfer. Preoperative angiography is important to delineate the vascular run-off and the availability of receptor vessels for the microvascular anastomosis. Large defects are covered with muscle or musculocutaneous flaps such as the latissimus dorsi and rectus abdominis muscles while smaller defects can be managed with gracilis muscle transfers. In an effort to decrease the morbidity of the muscle donor site, surgeons are now using perforator free flaps to reconstruct wounds. The most common perforator flap used is the anterolateral thigh (ALT) flap. The muscle flaps are still preferred for large, deep wounds with bone contamination, while the perforator flaps are good for smaller wounds with minimal dead space and contamination.

What Are the Outcomes of Management of the Mangled Extremity?
Data from the Lower Extremity Assessment Project (LEAP) indicate that both amputation and complex lower extremity reconstruction of limb-threatening injuries yield similar functional results.(58–60) The average treatment cost of a patient with a limb-threatening extremity injury for the 2 years following injury in 2002 dollars is $84,207.00. The average cost of all amputations is $91,106.00 compared with $81,316.00 for all reconstructions at 2 years following injury. The projected lifetime cost for care of amputation patients ($509,275.00) however is more than three times higher than that for patients with extremity reconstruction ($163,282.00). The difference in cost is due primarily to the cost of lower extremity prostheses.(61)

Evidence-Based Recommendations for Management of the Mangled Extremity
Unfortunately, Class I studies to guide management of the mangled extremity are lacking.(62) The principles in Table 18.1 should guide management based on the available evidence:

1. Resuscitation and treatment of life-threatening injuries should precede management of all extremity problems except control of exsanguinating hemorrhage.
2. Restoration of vascular perfusion of the ischemic injured extremity should be accomplished as soon as possible. Delay in restoration of perfusion for more than 6 h decreases the chance of limb salvage.
3. Expeditious pre-operative vascular imaging should precede exploration of the injured extremity. However, if undue delay is anticipated, the patient should proceed directly to

Table 18.5 Evidence-Based Recommendations for Management of the Mangled Extremity.

Recommendation	Grade of Recommendation
1. Resuscitation and treatment of life-threatening injuries should precede management of all extremity problems except control of exsanguinating hemorrhage.	1A
2. Restoration of vascular perfusion of the ischemic injured extremity should be accomplished as soon as possible. Delay in restoration of perfusion for more than six hours decreases the chance of limb salvage.	1A
3. Expeditious pre-operative vascular imaging should precede exploration of the injured extremity. However, if undue delay is anticipated, the patient should proceed directly to exploration.	1C
4. There should be a low threshold for the use of stents to achieve immediate revascularization prior to skeletal stabilization if a simple vascular repair is not possible.	1B
5. Definitive complex vascular reconstruction should be deferred in the presence of cardiovascular instability or adverse local wound conditions.	1A
6. Arterial reconstruction above the popliteal fossa should be done with either reverse saphenous vein interposition grafts or PTFE synthetic graft when primary repair is not possible. There is no definitive evidence to support one conduit in preference to another above the knee. Arterial reconstruction in the popliteal fossa and distally should be performed with a reversed saphenous vein interposition grafts.	1B
7. Repair of the popliteal and common femoral veins is desirable if possible. Ligation of these veins is acceptable in a life-threatening situation.	1C
8. The decision to amputate rather than reconstruct a mangled lower extremity cannot be made on the basis of any known scoring system. Mature clinical judgment taking into account variables such as ischemia time, muscle necrosis, nerve injury, co-morbidities and wound contamination is the best guide for treatment at the present time.	1C
9. A liberal policy of four compartment fasciotomy is appropriate in the treatment of the mangled extremity.	1A
10. Exposed bone should be resurfaced with a well vascularized muscle flap.	1A
11. Lower extremity reimplantation is rarely indicated in the treatment of the mangled extremity.	1A

exploration. There is no Level 1 evidence demonstrating the best method of vascular imaging.

4. There should be a low threshold for the use of stents to achieve immediate revascularization prior to skeletal stabilization if a simple vascular repair is not possible.

5. Definitive complex vascular reconstruction should be deferred in the presence of cardiovascular instability or adverse local wound conditions.

6 Arterial reconstruction above the popliteal fossa should be done with either reverse saphenous vein interposition grafts or PTFE synthetic graft when primary repair is not possible. There is no definitive evidence to support one conduit in preference to another above the knee. Arterial reconstruction in the popliteal fossa and distally should be performed with a reversed saphenous vein interposition grafts.

7. Repair of the popliteal and common femoral veins is desirable if possible. Ligation of these veins is acceptable in a life-threatening situation.

8. The decision to amputate rather than reconstruct a mangled lower extremity cannot be made on the basis of any known scoring system. Mature clinical judgment taking into account variables such as ischemia time, muscle necrosis, nerve injury, co-morbidities and wound contamination is the best guide for treatment at the present time.

9. A liberal policy of four compartment fasciotomy is appropriate in the treatment of the mangled extremity.

10. Exposed bone should be resurfaced with a well vascularized muscle flap.

11. Lower extremity reimplantation is rarely indicated in the treatment of the mangled extremity.

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19 Damage Control Laparotomy

Brett H Waibel and Michael F Rotondo

A 22-year-old male presents via emergency medical system (EMS) to the emergency room after suffering multiple gunshot wounds 10 minutes prior. IV access was not attainable in transport. On arrival, the patient is confused with bilateral breath sounds, left better than right. Heart rate is in the 140s with palpable weak central pulses. Distal pulses are absent. The automatic blood pressure unit continues to attempt to obtain measurements without success. Exposure of the patient demonstrates three gunshot wounds; two 5 cm lateral and inferior to the right nipple and one inferior to the umbilicus. The patient is intubated with some difficulty due to trachea deviation to the left. A 40 French chest tube is placed in the right chest with 1,200 ml of blood returned. Two large bore intravenous lines are obtained and O-negative blood is transfused via a rapid infuser. With these maneuvers, the patient's vitals improve. Chest X-ray demonstrates two missiles in the right chest and an abdominal film shows a single missile overlying the right flank. Hematuria is noted on placement of the Foley catheter. The patient is prepared for the operating room for exploration.

What happens now?

HISTORY AND CONCEPT OF DAMAGE CONTROL LAPAROTOMY

Prior to the development of a field of trauma, treatment of physical injury was primarily the realm of the general surgeon. In many locations in the United States and the world, this is still the case. Because of this, complex multi-system injury was traditionally approached in a similar manner as other surgical problems. However, the trauma population has certain physiologic and anatomic characteristics not seen in the elective surgical population. The injuries obtained have a high destructive capability involving multiple body systems and cavities. Moreover, prolonged delays between injury and definitive care are not uncommon, which lead to significant deterioration of physiology from ongoing bleeding and visceral contamination. In contrast, elective surgical procedures usually involve single organs with limited collateral involvement and stable physiology. If bleeding or contamination occurs during the procedure, they are generally readily controlled. Finally, preoperative evaluation is different between the trauma patient and the elective surgical patient. The unstable trauma patient has no physiologic tolerance to undergo the extensive testing seen with the elective patient. Often, the unstable nature of the trauma patient even prohibits obtaining basic health information due to confusion or unconsciousness. These factors of altered physiology at onset, delay of presentation, complications from ongoing bleeding and contamination, and limited or absent preoperative medical history and evaluation are some of the major differences between the elective surgical patient and the trauma patient. Historically, attempting the more traditional approach of operating until the surgery is definitively finished resulted in ongoing bleeding from coagulopathy, unresuscitatable shock, and death in the early going or multiple system organ failure later in the course.(1, 2)

With the development of trauma as an area of specialization, evaluation of these traditional approaches came under fire. H. Harlan Stone did some of the original work in 1983.(3) He discussed aborting a laparotomy with intra-abdominal packing when nonmechanical bleeding developed due to coagulopathy. Others further developed this concept, such as Burch with packing of hepatic injuries, showing an improvement in survival with these basic damage control techniques.(4) Adoption of these ideas was slowed, however, due to belief that this was either a failure of surgery or shifting of work to other time periods or surgeons. Ten years latter, in 1993, Rotondo and Schwab proposed the next iteration of this concept under the description of "damage control."(5) The time sequence was defined along with the improved outcomes noted. Subsequently, the stages of damage control were refined and expanded to include the prehospital setting in preparation of the trauma patient.(6, 7)

While the concept of damage control was initially described for intra-abdominal trauma, it has been expanded to extra-abdominal injuries, such as thoracic and extremity vascular and orthopedic injuries.(8, 9) Recently, the current conflict in Iraq and Afghanistan has provided opportunity to extend the concept of damage control across multiple echelons of care in the Joint Theater of Operations and further challenge traditional resuscitation techniques in the exsanguinating patient.(10–12) The "damage control resuscitation" as discussed by Holcomb and Beekley includes aggressive use of rewarming techniques, control of acidosis, resuscitation with plasma at 1:1 ratios with packed red blood, and use of whole blood from a walking donor pool in theater.(13, 14) Also, use of recombinant Factor VIIa is aggressively used in theater. While many of these topics are currently debated toward efficacy, timing, and technique, the conflicts provide an opportunity to evaluate the efficacy of both the resuscitation techniques and the damage control approach. Initial evaluation at military levels 1 and 2 triage sites focus on identifying soldiers with immediately life-threatening injuries requiring exploration, with the primary goals of hemorrhage and visceral contamination control. Subsequent evaluations at higher-level echelons of care (similar to level I civilian centers) are concerned with definitive care and closure of the body cavities. Damage control techniques, along with other factors, have reduced the mortality of the wounded American soldier to the lowest of all its wars.(15)

INDICATIONS OF DAMAGE CONTROL

The damage control sequence revolves around identifying patients not physiologically prepared for a more traditional approach. In the traditional approach, the injuries were identified, and

Table 19.1 Indications for Damage Control Approach.

High-energy blunt torso trauma

Multiple penetrating torso injuries

Hemodynamic instability

Coagulopathy on presentation or during operation

Severe metabolic acidosis (pH < 7.2 or base deficit > 8)

Hypothermia on presentation (< 35°C)

Prohibitive operative time required to repair injuries (> 90 min)

Multiple visceral injuries with major vascular trauma

Multiple injuries across body cavities

Massive transfusion requirements (> 10 units packed red blood cells)

Presence of injuries better treated with nonsurgical adjuncts

bleeding and contamination were controlled. Definitive repair of the injuries was followed by closure of the abdominal wound. In "Damage Control", definitive repair and abdominal closure are delayed after control of hemorrhage and contamination in favor of recapturing the patient's physiology. After physiological reserve is recaptured in an ICU setting, definitive reconstruction of the injured organs occurs. Closure of the abdominal cavity may be further delayed in some circumstances.

The decision to undergo damage control should be made early in the operative process. This decision may even be made prior to patient arrival based upon information transmitted by EMS during transport. While prehospital hypotension can be resolved with resuscitation, it should be considered a warning of the patient being more severely injured and potentially unprepared for a prolonged operation.(16) In theory, a damage control laparotomy should last less than 90 minutes.(17) Thus, consideration of damage control should be made prior to physiological exhaustion and presentation of hypothermia, acidosis, or coagulopathy. Waiting for development of this lethal triad will reduce the likelihood of salvage (Table 19.1).

The triad of death; hypothermia, acidosis, and coagulopathy; along with other considerations, should be indications that an abbreviated "damage control" operation is mandated.(18, 19) These three conditions interact with one another to worsen ongoing hemorrhage (mechanical and nonmechanical) to create a spiral effect resulting in the death of the patient.(20) While no definitive cutoffs for these conditions exist, the surgeon should be in constant consideration of the overall condition of the patient. Temperatures below 35°C, pH less than 7.2 or base deficits of more than 8, and evidence of coagulopathy (either clinical or laboratory) are often used as general guidelines. The surgery should be aborted prior to development of these conditions if possible. A continuous interaction with the anesthesia team is necessary to identify the beginning of the spiral.

Other indications for damage control would be the presence of multiple injuries, either within the operative field or outside of it. The time required for definitive care of these injuries may be prohibitive given the physiology of the patient. Also, ongoing blood loss may not be immediately identifiable by the operative team, such as under the operative drapes from an extremity wound. This ongoing blood loss can accelerate the time to physiological exhaustion. As such, multiple injuries, especially those involving multiple body compartments, are a prime consideration for damage control procedures. Control

of hemorrhage should be treated as a continuum across body cavities and body regions, beginning with what is perceived as the most compelling source of bleeding. For example, with a combined thoracoabdominal wounding pattern, one must make a judgment based on available data relative to the most compelling source of bleeding; start there and move on expeditiously. These techniques lead to decreased operative times, blood loss, and thermal derangements, which could lead to an unsalvageable patient.

Other considerations include definitive repairs requiring prolonged surgical times or injuries which would benefit from nonsurgical adjuncts such as endovascular intervention to obtain hemorrhage control. One example would be with extensive damage to the head of the pancreas and duodenum requiring the "trauma Whipple." The multiple anastamosis required, especially with non dilated ducts, can easily lead to long operative times not well tolerated by the physiologically unstable trauma patient. Another example is ongoing bleeding from pelvic or hepatic injuries that may be best dealt with by angiographic embolization.(21) Moreover, the variability of physiological reserve across the patient population must be considered. The elderly, those with multiple comorbidities, and the very young have less tolerance of long operative times and need constant re-evaluation and consideration in the application of the damage control approach.

As stated, the indications for damage control surgery revolve around identifying those patients without the ability to tolerate a prolonged, traditional approach to surgery. Those patients with entry into the triad of death or injuries requiring prolonged repair beyond their physiological reserve are the main candidates for damage control surgery. It is the goal to abort operating in these patients prior to physiological exhaustion if possible. Thus, the damage control laparotomy is limited to control of hemorrhage and visceral contamination in order to move the patient into an environment for physiological recovery in preparation for definitive repair. It makes sense that as resuscitative techniques improve and physiologic control prior to operator control becomes better understood that the need for the application of damage control surgery may actually decrease.

DAMAGE CONTROL SEQUENCE

Traditionally, damage control focused upon intra-abdominal injuries with the initial sequence (Part 1) obtaining control of ongoing hemorrhage and visceral contamination. Part 2 involved resuscitation of the patient in preparation of definitive repair (Part 3). Finally, (Part 4) closure of the abdominal cavity was achieved. These concepts have been refined to include the prehospital setting (Ground Zero) and extra-abdominal wounds today (Figure 19.1).

Ground zero: Prehospital care/initial resuscitation

Prehospital care is important in preparation of the severely injured patient. The rapid transport of patients from injury to definitive care with minimal delays can have a marked effect upon the outcome.(22) This phase is built upon the fundamentals of Advanced Trauma Life Support (ATLS). Obviously, unstable airways need to be supported and breathing deficits may require adjuncts like tube thoracostomy. Circulation should be assessed and ongoing
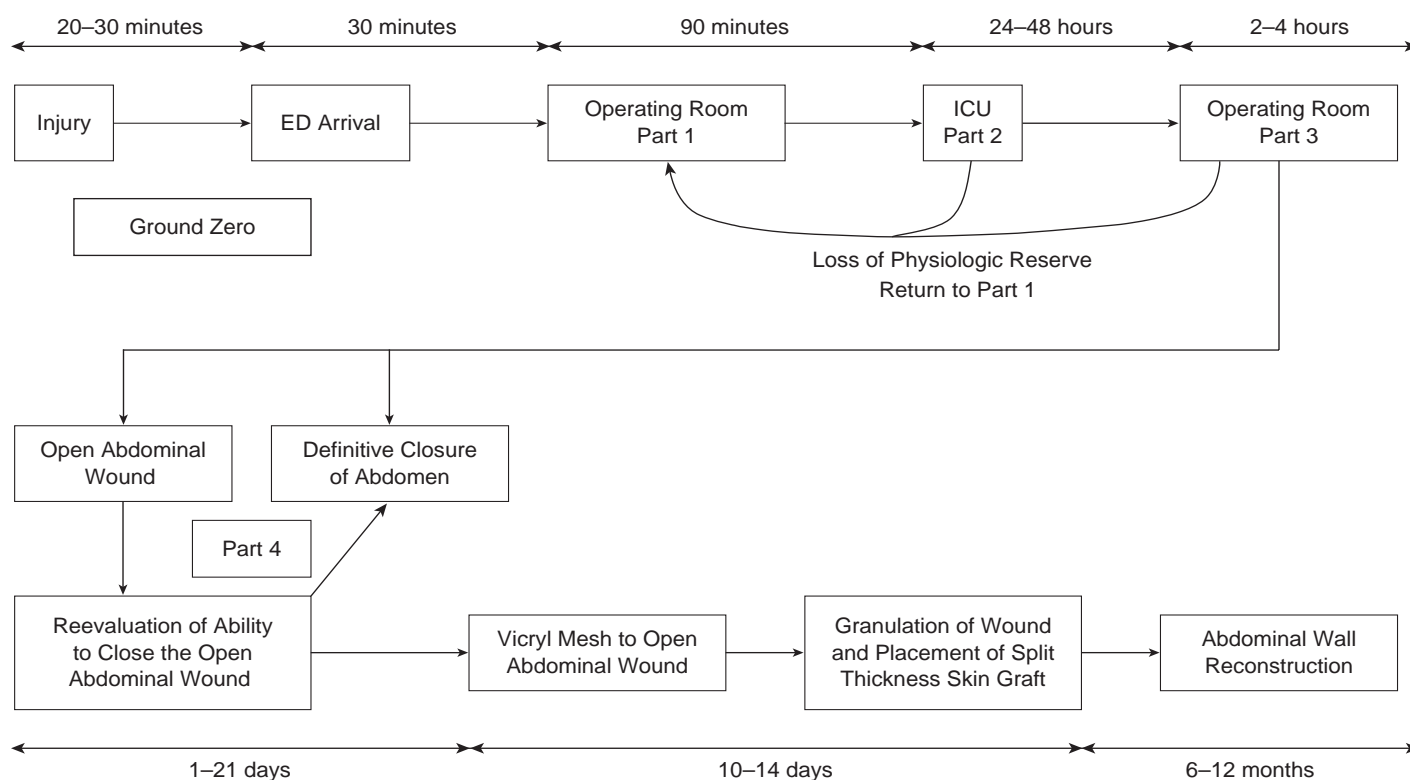
Figure 19.1 Damage Control Timeline.

hemorrhage losses should be controlled with realignment of fractured limbs and point pressure application to ongoing bleeding sites. Resuscitation should begin in this phase via large bore intravenous or intraosseous catheters. This has been preformed with crystalloids (isotonic) and/or packed cells. Traditionally, resuscitative efforts were aimed at increasing hydrostatic pressure to improve tissue perfusion. However, it is now recognized that this may lead to clot disruption and hasten bleeding. This only serves to prolong and repeat the ischemia-reperfusion cycle. Rather, resuscitation to a systolic of 80–90 mmHg is likely more prudent while the patient is being moved expeditiously to the operating room.(13) Recently, discussion has begun on including fresh frozen plasma in differing ratios to packed cells to alter the outcome in the severely injured trauma patient and is hotly debated.(14, 23, 24) Communication between the transporting crew and the hospital personnel is vital for preparation in receiving the unstable trauma patient. Good communication allows resources to be mobilized to decrease evaluation times and delays to the necessary treatment areas.

At arrival to definitive care, a rapid evaluation is necessary. Adjuncts such as Focused Abdominal Sonography in Trauma (FAST), diagnostic peritoneal lavage (DPL), tube thoracostomy, along with imaging studies, are helpful to rapidly identify the source of ongoing hemorrhage. The most useful imaging studies in the unstable patient are the supine chest and pelvis films. The five sites of hemorrhage most likely to result in an unstable patient are intrathoracic, intraperitoneal, pelvic/retroperitoneal, long bone fracture sites, and externally. Physical examination, along with these imaging studies and adjuncts, can rapidly identify the etiology of ongoing hemorrhage. This knowledge is helpful in preparation for the next phase of damage control.

This phase should be rapidly performed with a goal time of 20 minutes or less.

Part 1: Control of Hemorrhage and Contamination
This phase involves rapid control of mechanical hemorrhage and visceral contamination. Full exposure of the injuries is paramount to identification of ongoing hemorrhage and visceral contamination. After evacuation of blood, packing of the abdominal cavity is undertaken to control ongoing hemorrhage and contamination and allows the anesthesia team time for resuscitation. Cell savers provide the ability to wash and transfuse shed blood during the case. Care should be taken as these blood products also lack clotting factors and can lead to a coagulopathy if not replaced. Numerous maneuvers, including Kocher, Mattox, Aird, and Cattell-Braasch, allow for exposure of the retroperitoneal structures as needed. Identification of the injured vasculature is required to determine the correct technique in controlling the bleeding. Some solid organs, such as spleen and isolated kidney, are sacrificed in damage control if repair prolongs surgical times. Of note, control of the vascular pedicle of solid organs, if available, is an excellent means of hemorrhage control during damage control. Ongoing vessel hemorrhage can be controlled with ligation in many circumstances; however, repair is required with vessels that supply end organ perfusion or outflow of critical organs. Some examples would include the portal vein and suprarenal vena cava. If ligation is not possible and repair times are prohibitive, shunting techniques exist that are viable options for temporary restoration of flow during the resuscitative phase.(25) These techniques have been described most recently in reports from the

Figure 19.2 Taxi cab hailing position. Note abduction of arm to 90° and torso rotation to 30° anterior to coronal plane.

Iraqi war.(26–28) Hepatic and retroperitoneal injuries may also require packing for hemorrhage control.

Intestinal contamination is yet another primary concern in this phase. This is easily accomplished with quick suture closure of the visceral wound or stapling techniques to remove the involved segments. Formal repairs are avoided during this phase to limit operative time in favor of entry into the next phase of damage control. The intestines are left in discontinuity during this phase with plans for definitive repair after full resuscitation.

Temporary abdominal closures are used to further decrease the operative time in the unstable patient. One should attempt to limit the initial operation to less than 90 minutes in damage control. Temporary closures allow for rapid reentry into the abdomen while preserving fascia for latter definitive closure of the abdominal wall.

Frequently, however, determining which body cavity to enter can be complicated when multiple cavities are involved. The adjuncts of FAST, DPL, tube thoracostomy, and imaging studies can help, but are not absolute. Diaphragm injuries can allow for transmission of blood between cavities. Furthermore, if the ongoing bleeding is felt to be from pelvic injuries, angiography with embolization may be the initial treatment.(29) However, some debate has been recently created concerning the use of preperitoneal packing in unstable pelvic injuries instead of angiography.(30) A best guess estimate of the source of ongoing, life-threatening hemorrhage should dictate the course of action. Generally, fluid in the peritoneal cavity with hypotension will lead to a celiotomy, while large volume loss from tube thoracostomy (> 1,500 ml) or ongoing drainage (> 200 ml/h over 3–4 h) indicates the need for a thoracotomy.

Positioning in the operating room should always consider the possibility of multiple compartment injuries. While the supine position is generally best for abdominal explorations and lateral decubitus positions allow for the best intrathoracic exposure, the combined thoracic/abdominal compartment injuries are not suited best by either. Often, a middle ground will allow for reasonable exploration of both compartments. This is obtained with placing the patient primarily in a supine position with the chest laterally rotated 30° anterior to the coronal plane with folded blankets for further exposure of the chest wall to one side. The arm can be abducted to 90° into taxi cab hailing position or laterally with inclusion into the field if manipulation is required. Obviously, the chest is not raised if an indication of involvement of one hemithorax over the other is not made preoperatively. Supine position also allows for sternotomy if needed, and full preparation from neck to knees should be completed for all trauma laparotomies (Figure 19.2).

Part 2: Resuscitation

Recapturing physiologic reserve is the next goal. This is done by aggressive resuscitation along with correction of hypothermia, acidosis, and coagulopathy. Fluid choices can affect the acid–base balance, which may further affect coagulopathy. Normal saline, in large volumes, will lead to a nonanion gap metabolic acidosis.(31) While Lactated Ringer's has not been associated with these acid–base disturbances, animal evidence does exist for activation of the immune system, which may further lead to cellular injury. In the last few years, new evidence has been produced from the military, and now from the civilian sectors, supporting a larger use of plasma in the resuscitation of these damage control patients. (13, 14, 24, 32) Many are now recommending closer to a 1:1 red blood cell to fresh frozen plasma ratio of transfusion compared to the traditional 4:1 transfusion ratio. However, survival benefits have not been found by all, nor has the best ratio of packed cells to plasma been elucidated.(23) Most of the published literature outside of the military appears to support the aggressive use of plasma in massive transfusion protocols (> 10 units packed red blood cells) at a closer ratio of 1:1.

Recombinant Factor VIIa is also finding a place in massive transfusion protocols. Most of the literature is anecdotal or from animal models, however, some retrospective information is again arriving from the military sector supporting its use.(33–35) The exact timing and dosing of this medication remains controversial. Also, the potential for thromboembolic events is present with this medication.(36) Other complications of hyperglycemia and

electrolyte disturbances are also common during this period and should be corrected in an expedient fashion. Insulin drips for the correction of hyperglycemia are becoming commonplace in the ICU since Van den Berghe's landmark paper in 2001.(37)

Multiple end points of resuscitation have been proposed in the past to help with resuscitation; however, no single test is a panacea.(38–40) Resuscitation is continued until the patient has resolved the shock state with resumption of end organ perfusion and normalization of acidosis and coagulopathy. Only in this setting should the patient continue on to reoperation for definitive repair of injuries. While medicine literature has generally stated the lack of efficacy of Swan–Ganz-based resuscitation based upon mortality outcomes, evidence exists in the surgical literature supporting its use, especially right ventricular end-diastolic volume index (RVEDI) pulmonary artery catheters.(41–43) We have found advantage in their use in our own practice to help direct volume resuscitation along with pressor selection and use in difficult resuscitations. Other adjuncts, such as angiography with embolization, may be necessary during this phase to deal with hemorrhage that would be difficult to surgically control, such as hepatic injuries or pelvic hemorrhage. Generally, reoperation for definitive repair can be performed in 24–36 h after the initial operation, once physiologic and laboratory parameters normalize. Failure to regain a stable physiology is an indication that a missed injury or ongoing hemorrhage is present. This will actually accelerate the return to the operating room for re-exploration as Part 1. Hence the cycle of damage control Parts 1 and 2 may repeat.

Care should be taken in the resuscitation period to protect or limit iatrogenic injury to the patient. For example, inappropriate ventilator strategies can lead to problems for the patients. While several ARDSNet studies exist discussing the use of reduced volumes and pressures to improve outcomes with mortality in Acute Respiratory Distress Syndrome (ARDS), the ventilator itself can be a major inducer of pulmonary injury and ARDS.(44, 45) In general, lung protective strategies with tidal volumes of 4–6 ml/kg of lean body weight should be employed. Commonly, sedation and analgesics are needed to help promote synchrony between the patient and the ventilator when these protective strategies are used. A small percentage of patients may require neuromuscular blockade to achieve this synchrony; however, a blanket use of these medications is not recommended.(46) Their use has not shown improvements in outcome in mortality or oxygen consumption in ARDS patients in randomized, controlled studies. Also, ICU-related myopathy and neuropathy is increased with their use.

Compartment syndrome is not uncommon in these damage control patients. Often, this effect is noticed at the time of the initial surgery with the inability to return the abdominal viscera into the peritoneal cavity due to edema and distention. However, with aggressive volume resuscitation, this complication may develop in the hours following completion of Part 1. While a more detailed discussion of this complication will be covered in a latter portion of the chapter, it should be stressed that placement of a temporary abdominal closure is not a guarantee that the patient will not develop abdominal compartment syndrome. Routine monitoring of bladder pressures along with renal function and airway pressures is necessary to identify the development of this

Table 19.2 Sequence of Definitive Repair.

Careful removal of packs
Inspection/identification of all injuries
Control of remaining errant bleeding points
Definitive gastrointestinal repair
Thorough abdominal washout
Avoid stomas and tube enterostomies, if possible
Nasoenteric feeding tube placement
Closed suction drainage, if needed
Temporary versus definitive abdominal wound closure
Tracheostomy, if needed
Radiographic evaluation of abdomen for retained packing

problem. This can be done with any Foley type urinary catheter that allows retention of a small volume of saline (50 ml) irrigant placed in the bladder and transduction of pressures.(47) While intra-abdominal hypertension is defined with pressures above 10 mmHg, abdominal compartment syndrome is generally not seen clinically until pressures above 30 mmHg. However, it should be noted this is a clinical diagnosis, and patients with pressures below 30 mmHg have developed abdominal compartment syndrome. Delayed identification and treatment leads to worse outcomes.

Part 3: Definitive Repair of Injuries
Once fully resuscitated and physiologically normalized, the patient is prepared for the longer operative times required for definitive repair. Also, the time spent in resuscitation can allow for preoperative planning for the definitive repair (Table 19.2). On arrival to the operative suite, the packs placed to help with hemorrhage control in the first surgery are carefully removed. A thorough re-evaluation of the abdomen is performed, including evaluation of retroperitoneal structures if needed. It is in this setting that a complete categorialization of injuries is made. Any remaining bleeding points should be addressed in an expedient manner. If the hemorrhage is uncontrollable, or patient demonstrates an inability to undergo a prolonged operation, it is appropriate to return to Part 1 with control of hemorrhage and gastrointestinal contamination as the primary goals.

Once a complete inspection of the abdomen (or appropriate body cavity) has been performed, definitive repair is undertaken. The repairs required depend upon the nature of the injury and organ system involved. It is during this part that gastrointestinal continuity is reestablished. Some general concepts to consider include limiting use of prosthetic material in a contaminated wound and the possible need to return to the operating room for further washouts of a contaminated cavity prior to definitive closure of the cavity. Finally, some repairs can be considered in this part that would not have been undertaken in a traditional, single operative setting. For example, isolated colon injuries in the unstable patient or in presence of large contamination have traditionally been treated with an ostomy. In a resuscitated patient, one might consider a primary anastamosis, especially if the patient would poorly tolerate the ostomy.(48) The abdomen should be thoroughly irrigated after completion of the repair of the injuries.

Table 19.3 Closure of Open Abdominal Wounds.

Immediate term
    Skin closure only
    Home-made vacuum-assisted dressing

Intermediate term
    Sequential fascial closure
    Sequential skin closure
    Interpositional mesh placement
    Vacuum assisted abdominal dressing

Long term
    Interpositional Vicryl mesh placement followed by split thickness skin grafting and abdominal wall reconstruction

While some studies exist showing percutaneously placed feeding tubes may be safe, even with open abdominal wounds, stomas and tube enterostomies should be generally avoided due to complications that they can introduce.(49–51) The abdominal wall of the critically ill patient can undergo considerable flux, especially with the enlarged body habitus noted in this day compared to decades past. Nutritional support is extremely important in the critically injured patient. Consideration of a post-pyloric or post-ligament of Treitz nasoenteric feeding tube should be made on all these patients. These allow for ongoing enteral access in these critically ill patients. The initiation of enteral feeds should be held in the unstable patient due to risk of intestinal ischemia and necrosis.

Drainage of cavities, when necessary, should incorporate closed suction systems. While definitive closure of the abdomen is desired, it is not always accomplished at this time. If a temporary abdominal closure is required, one should strive to ensure the intestines are placed below the level of the fascia. Omentum is useful in providing coverage of the abdominal viscera to further protect it from injury. Fascial breeches should be avoided if possible. Further discussion on the management of the open abdominal wound can be found in the next section of this chapter.

Consideration of a tracheostomy should be made during this portion of the case.(52–58) Often, given the labile post-operative course of these critically ill patients, pulmonary dysfunction via acute lung injury or ARDS can begin to manifest itself during hospital days 2 and 3. The tenuous state of the patient to disruption of the ventilator circuit under these conditions makes tracheostomy impossible until the patient has begun to improve, which may take several weeks to achieve. Early placement of the tracheostomy in select patients can allow for a much more secure airway during these times of pulmonary dysfunction.

Finally, before definitive abdominal closure, an X-ray of the abdomen is needed. Given the rapid nature of the initial surgeries and placement of abdominal packing, closing counts can become inaccurate and should not be trusted. An abdominal film provides a permanent record of complete pack removal.

Part 4: Open Abdominal Wounds and Definitive Closure of the Abdomen

Definitive closure of the abdominal wall can be a complicated subject in damage control surgery (Tables 19.3). Approximately 40–60% of patients who undergo damage control cannot be primarily closed initially.(59, 60) Temporary closures are required in patients who will require multiple operations for washouts or repair of injuries and those with distention of the underlying viscera. One way of determining if a patient has resolved the visceral distention adequately is to measure airway pressures while pulling the fascia into position with Kocher clamps. If the airway pressure rises by over 10 mmHg, generally the abdomen should not undergo primary fascial closure.

Multiple temporary abdominal dressings are available. These include use of skin closure, interpositional mesh techniques, and vacuum-assisted dressing techniques.(59–66) Temporary abdominal closures should be selected in order to keep the viscera contained while preventing further contamination of the abdominal cavity. They should seal the abdomen and control the effluent from the wound to preserve the skin. Also, the dressing should not create tension on the abdominal wall or increase the intra-abdominal pressure. Finally, the fascia should be preserved for future closure of the abdominal wall.

In the immediate setting, such as Part 1 or 3, when the abdomen cannot be closed, temporary closures primarily involve skin closure techniques, silo placements, or "home-made" vacuum-assisted dressings. Skin closure with suture or towel clipping is the easiest abdominal closure that maintains abdominal domain with avoiding injury to the fascia. However, the closure is rarely watertight and creates radiographic artifact (with towel clipping) that complicates adjuncts like angiography. This should be considered mainly a temporary closure to allow fast movement to another therapeutic modality. Silo techniques, such as the Bogota Bag, while instrumental in the past, have generally fallen to the wayside in the present era. The dynamic properties of a vacuum-assisted dressing make it more useful. A quick and cheap vacuum-assisted dressing can be created from common surgical items. An impervious dressing is placed between the viscera and the fascia initially. This can be created from a perforated, sterile plastic draping, or by a surgical towel sandwiched between layers of Ioban (3M, St. Paul, MN) drapes. The sandwiched surgical towel also provides some weight to help maintain the viscera within the abdominal cavity. An interpositional layer of Kerlex (Kendall, Mansfield, MA) rolls are placed over this layer and embedded with closed suction drains. This layer allows fluid to exit the abdomen for collection while maintaining a negative pressure within the abdomen and dressing. A final layer of Ioban draping is then placed to provide a seal to the system to maintain a watertight closure for skin maintenance and suction is applied to the suction drains (Figure 19.3).

When definitive closure is delayed further beyond the initial presentation, other techniques for management of the open abdominal wound are commonly employed. Sequential closures of the open abdominal wound with temporary abdominal dressings are commonly employed when possible. Obviously, closure of the fascia is preferable to skin closure, but removal of the open abdominal wound is paramount when possible. This is due to the high mortality rates seen when early closure of the open wound in not achieved. While vacuum-assisted dressings are still popular as sole therapy, and commercial varieties exist such as the KCI V.A.C. (Kinetic Concepts, Inc., San Antonio,
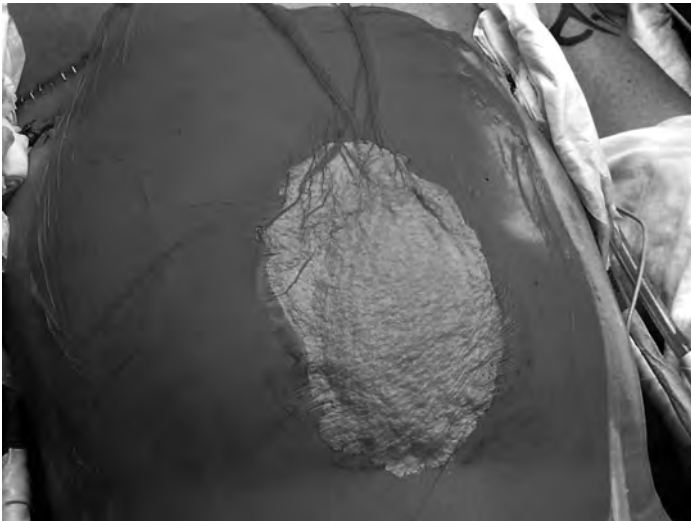
Figure 19.3 "Home made" Vacuum assisted dressing.

Figure 19.4 KCI V.A.C. System.

TX), these are often used in conjunction with interpositional meshes (Figure 19.4). Several studies exist showing decreases in multiple organ system failure, abdominal compartment syndrome, necrotizing fasciitis, and enterocutaneous fistula in several different patient populations.(67–69) Recurrent abdominal compartment syndrome is possible with these techniques during aggressive volume resuscitation. Some meshes are prone to issues with tearing due to low tensile strengths: Vicryl (polyglactic acid, Ethicon, Somerville, NJ) and Dexon (polyglycolic acid, Davis and Geck, Danbury, CT). Polypropylene meshes (Marlex, Bard, Billerica, MA; Prolene, Ethicon, Somerville, NJ; Surgipro, US Surgical, Norwalk, CT), while stronger, create an inflammatory reaction to the underlying viscera with higher fistula rates up to 15–50%.(70) Gore-Tex (polytetrafluoroethylene, Gore and Associates, Flagstaff, AZ) mesh, while nonadherent and strong, has a high infection rate along with expense. Overall, most patients will eventually undergo closure of the abdominal wall if patience is practiced.(62, 71) This may involve primary fascial closure or more advanced surgical options such as allograft or mesh placement. Closure rates with interpositional meshes are around 37–88%, with most in the lower end of the range.(62, 67, 72, 73) Vacuum-assisted abdominal closures seem to have higher closure rates (around 70%) without increase in morbidity or mortality.(60, 73) Prosthetic mesh placement with fascial releases or skin flaps is avoided during this stage for multiple reasons. They carry increased infection and/or wound complication rates. Also, they detract from or complicate abdominal wall reconstruction options at later dates.

Some patients cannot be closed during their initial presentation. These patients will require placement of absorbable interpositional mesh (Vicryl) and await granulation tissue to appear for successful split thickness skin grafting (10–14 days generally) (Figure 19.5). After approximately 6–12 months, the skin graft will fall away from the underlying viscera (Figure 19.6). This will signal the time that abdominal wall reconstruction can be undertaken. Generally, one should not wait beyond 12 months, as loss of domain becomes a great issue beyond this point. Plastic surgery may be required for placement of tissue expanders or flaps if soft tissue coverage for abdominal reconstruction is an issue.(70, 74) If sufficient fascia remains to allow primary closure, this is done with possibility of mesh onlay. When insufficient fascia is present, inlay mesh placement (allograft or prosthetic) in a subfascial or retrorectus position and/or component separation techniques (via fascial releases) are required for closure (75, 76) (Figure 19.7). Generally, allograft is reserved for wounds with higher potential for contamination, such as combined procedures with ostomy reversal.

COMPLICATIONS

Complications associated with damage control generally revolve around two time periods: those during the initial surgical interventions and resuscitation and those during the open abdominal phase. Many of the initial complications are secondary to the consequences of shock, injury, and resuscitation and are discussed in other chapters. Some issues such as missed injury, intra-abdominal infectious issues, and abdominal compartment syndrome are found early in the damage control patient. The later complication of enterocutaneous fistulae is primarily due to treatment of the open abdominal wound.

Missed injuries are possible given the situation of the initial exploration. Some injuries are more common due to anatomy.

Figure 19.5 Interpositional vicryl mesh placement. A: Vicryl mesh with visceral structures covered by omentum. B: Granulating wound bed prepared for split thickness skin graft.

Figure 19.7 Component Separation. Note release of anterior oblique fascia to allow closure in midline.

Figure 19.6 "Pinch Test." Note that split thickness skin graft not adherent to underlying viscera.

These include injuries to the diaphragm, retroperitoneal structures (duodenum, ureters, bladder and rectum), and difficult to expose structures (posterior wall of stomach, pancreas, GE junction, retroperitoneal colon, and mesenteric border of bowel). Repeated examination can help ameliorate these issues.(77–79) Radiographic evaluation of the abdominal is also important in surveillance for retained sponges, which can be missed easily given the conditions of the original operation and serial reoperation. A routine abdominal film prior to definitive closure of the abdomen is a wise consideration in patients with abdominal packing or damage control procedure. It is our observation the unusual vascular injury or insufficiently controlled vascular injury invariably lead to death of the patient. The damage control approach is NOT a substitute for complete injury identification and control.

Packing of the abdominal cavity is often done with hepatic and retroperitoneal injuries. Intra-abdominal infection rates vary from studies from 10 to 70% and are probably related to length of time that packs are retained.(80–82) However, the interval between washouts is variable depending upon the situation with the patient. Increasing the interval between washouts appears to increase the infection risks, but decreases the risk of injury to the viscera and fistula formation from manipulation. The usual surveillance methods and therapies can be used in the patient who develops an intra-abdominal infection. Cumulative review reveals that the intra-abdominal abscess rate in these patients is in excess of 35%. Due to the complex infectious picture in these patients, we recommend weekly abdominal computed tomography (CT) scan to survey for abscess in those patients with persistent fever or leukocytosis. Other infectious disease issues associated with the critically ill patients are also common in the damage control patients. These include ventilator-associated pneumonia and catheter related infections, which will be discussed in other chapters.

Abdominal compartment syndrome is the clinically significant presentation of intra-abdominal hypertension with increased pulmonary ventilatory pressures, oliguria, and hypotension. (83) The pressure needed to create this clinical compromise is variable between patients. Risk factors include severe hemorrhagic shock, damage control, fascial closure after damage control, and elevated penetrating abdominal trauma index. Several physiological variables evaluated that correlate with abdominal compartment syndrome include high pulmonary peak pressures and low gastric mucosal pH.(84) An aggressive resuscitation has also been associated with development of abdominal compartment syndrome in several studies. Volumes exceeding 10 l of crystalloid, 10 units of packed cells, 0.25 l/kg of crystalloid, or 6 l of crystalloid or units of packed cells in 6 h have been associated with the development of abdominal compartment syndrome. An incidence of abdominal hypertension varies between 5 and 30% among studies depending upon the patient population and definition used.(85, 86) The tighter closures, including primary fascial closure, are associated with higher incidence of abdominal compartment syndrome along with greater incidence of death and complication with ARDS and multiple organ failure. (67, 87, 88) Recurrent abdominal compartment syndrome can occur in patients treated with temporary closures. A higher mortality is associated with these patients compared to those with an open abdomen and no development of abdominal compartment syndrome.(89) Thus, constant awareness of the issue is required in order to properly treat these patients. Obviously, the treatment for this syndrome is decompression of the abdominal cavity, but delays in identification and initiation of therapy carry greater morbidity and mortality.(90) Survivors of an open abdomen with planned ventral hernia feel decreased levels of physical, social, and emotional health. However, with definitive abdominal reconstruction, these levels return to the baseline of the general population.(91)

Enterocutaneous fistula rates depend largely upon the nature of the injuries, the extent of bowel manipulation, and the closure and care of the open abdominal wound. Overall, the rate of fistulas with open abdominal wounds appears to be around 1–15%, but higher fistula rates have been reported in some series.(59, 92) While the soft, absorbable meshes (Vicryl) have fistula rates around 5%, the more reactive, stiff meshes like polypropylene have higher fistula rates up to 50%.(70) These fistulae are generally more difficult to deal with than typical post-operative fistulae. These tend to be "entero-atmospheric fistula" occurring within the granulating wound. This makes control of the fistulae difficult, and they have a low nonsurgical closure rates of about 25%. (62)While prevention of the fistula is optimal, once they occur, standard therapy with bowel rest and parenteral nutrition should be started. The caustic output from the fistula should be controlled with suction drains and frequent dressing changes. However, even the best available wound management techniques fall short of satisfactory. Skin grafting can be beneficial also. While some of the graft may be lost due to the secretions, if adequately controlled, the skin will mature around the fistula allowing enterostomal appliances to be placed for control of the fistula output in a manner similar to an ostomy. Closure of these fistulae generally is delayed until the time of abdominal wall reconstruction at 6–12 months.

CONCLUSION

Given the patient's presentation at arrival, the surgeon decides to proceed with a damage control operation. Initial evaluation is somewhat mixed between chest and abdominal sources of ongoing bleeding. The surgeon decides that the abdomen is the primary source of ongoing hemorrhage, but places the patient in taxicab hailing position in case a thoracotomy is needed. This decision is made based upon the limited output at present from the chest tube along with rapid potential for evaluation of abdominal injuries via celiotomy. Damage control approach is made based upon the presentation of the patient is shock with multiple penetrating injuries across multiple body compartments.

On entry into the abdomen, a large volume of blood is encountered with hematoma in zone I and right zone II of the retroperitoneum is encounter. A Cattell–Braasch maneuver is performed after evacuation of the blood and packing of the abdomen. An injury to the inferior vena cava (IVC) and hilum of the right kidney is encountered. The kidney is removed and IVC injury repaired with simple lateral venorrhaphy. At this point, major hemorrhage is controlled in the abdomen. The viscera are evaluated and two injuries to the small intestines are removed with stapling. The bowels are left in discontinuity. During the operation, an acidosis was identified along with a mild coagulopathy. Hypothermia was aggressive treated in the operating room with environmental controls. After a quick washout and packing of dissection surfaces, a temporary, "home-made" vacuum-assisted abdominal dressing is placed.

During the case, the chest tube evacuates 1,000 more milliliters of blood. A right anterior-lateral thoracotomy is performed in the sixth intercostal space. A non-anatomic stapled wedge resection of the right middle lobe is performed along with stapled tractotomy of the missiles' passage to expose an arterial injury within the parenchyma of the lung, which was controlled with suture ligature. The missiles do not approach the central hilum and pericardium. Two 40 French chest tubes are placed under direct visualization and the chest is closed. Operative time was 90 minutes. The patient is taken to the ICU, where resuscitation is continued.

In the ICU, the patient continues to require a volume resuscitation with several liters of lactated ringer's, packed red blood cells, and fresh frozen plasma. This resuscitation was guided by multiple modalities, including RVEDI pulmonary artery catheter guided volume resuscitation and clearance of acidosis. Rewarming was continued in the ICU using environmental controls along with fluid warmers for intravenous fluids. By the next morning, the patient has cleared his lactates with good renal function; however, decreases in pulmonary

compliance are noted. Intra-abdominal pressures, measured via bladder pressures, are mildly elevated at 12 mmHg and the abdomen is soft on examination. No other signs of abdominal compartment syndrome are noted. Chest tube output has been minimal with no retained hemothorax on X-ray.

With physiology is normalized, he is returned to the operating room for definitive repair. The intra-abdominal packing is carefully removed and thorough evaluation of the abdomen is made. The intestinal continuity is reestablished and abdomen is washed out again. No further intra-abdominal injuries are noted on reoperation. However, the abdominal cavity is unable to be closed due to increases in abdominal pressure when attempts to bring the fascia together are made. A naso-duodenal feeding tube is placed for enteric access. Another temporary vacuum-assisted dressing is placed. Given the changes in pulmonary compliance and large volume resuscitation, along with inability to perform a definitive abdominal closure, an open tracheostomy is performed at this operation.

Further attempts to close the abdomen are made in the ensuing week, without success. During this period of time, the pulmonary compliance continues to worsen with development of an acute lung injury in addition to the penetrating injury. This prolongs the patient's ventilator requirements. The decision is made for interpositional mesh placement and subsequent split thickness skin grafting. Prior to definitive closure with Vicryl mesh, radiographic imaging confirms that all laparotomy pads have been removed.

The hospital course is further complicated by the subsequent development of a leukocytosis and fever. Usual ICU infectious monitoring, including cultures and bronchoscopic BAL, are performed. In addition, CT imaging of the abdomen shows the development of an intra-abdominal abscess in the pelvis that requires drainage via interventional radiology. After placement of the skin graft on the open abdominal wound, difficulties are created with a colocutaneous fistula that develops from the transverse colon with the graft site. While secretions are difficult to control, the skin graft eventually matures to allow placement of a stomal appliance to the fistula.

Eventually, the patient improves with resumption of normal enteric function, discontinuation of ventilator support, and resolution of infectious complications. Plans are made at discharge for close follow up with preparation for abdominal wall reconstruction and fistula takedown in 6 months to a year.

Grading of Literature.

Issue	Level of evidence	Reference(s)
Improvement of outcomes with damage control	1A	(1–9, 15, 48)
Limiting time of laparotomy to 90 minutes in damage control	2C	(17)
Indications for damage control surgery	1B	(16, 18–21, 30)
Use of damage resuscitation in critically injured patients	1C	(10–14, 23, 24, 31, 32)
Shunting of vascular injuries in severe traumatic injury	1C	(25–29)
Use of recombinant ractor VIIa in severely injured trauma patients	2B	(33, 36)
Use of end points of resuscitation in Part 2 of damage control	2B	(38–43)
Use of protective lung strategies in damage control trauma patients	1B	(44–46)
Monitoring of intra-abdominal pressures/Intra-abdominal hypertension and abdominal compartment syndrome	1A	(67, 47, 83–91)
Avoiding use of ostomies or feeding jejunostomies in trauma patients	2C	(49, 50, 51)
Early tracheostomy in trauma patients	1C	(52–58)
Management of open abdominal wounds	1B	(59–76)
Need for vigilance for missed injuries in damage control patients	1B	(77–79)
Need for removal of packing within 48 h/intra-abdominal abscess formation	1B	(80–82)
Management of enterocutaneous fistulae in the open abdomen	2A	(59, 62, 70, 92)

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20 The pulseless trauma patient

Reuven Rabinovici and Horacio Hojman

A male in his 20s is brought by his friends to the Emergency Department after being stabbed in the chest. They report that the exact time of injury is unknown and that the patient was found unresponsive approximately 15 minutes ago. On examination, the patient is unresponsive, pulseless, and has a stab wound 2 cm medial to the left nipple.

One consequence of the progressive evolution of modern pre-hospital systems and highly specialized trauma centers is the need to care for trauma patients that historically had no prospect for continued life. These victims are brought to the hospital in profound or complete cardiovascular collapse, and only dramatic "out of the box" efforts, which instantly address the life-threatening injuries and physiological derangement, can provide salvage.

These ultra urgent situations pose significant challenges to both the trauma surgeon and the hospital system. First, they force the physician to take immediate "life and death" decisions under tremendous pressure. These decisions require early recognition of the "near death" situation, knowledge of preset management guidelines, excellent surgical skills, and sharp clinical intuition. Second, these critical scenarios mandate trauma centers to instantaneously provide all the resources required for performing heroic life-saving procedures, including skilled nurses, surgical instrumentation in the trauma room, rapid blood infusers/warmers, and a massive transfusion protocol.

The paradigm of surgical intervention in patients at or just above the threshold of death is resuscitative thoracotomy (RT). This procedure is bold and exceedingly invasive. However, it is the only course of action that can restore physiological reserves rapidly enough to allow survival of patients in extremis. RT, also termed "Emergency Department thoracotomy" or "emergency thoracotomy," has evolved mainly through trial and error efforts by individual surgeons practicing in high-volume trauma centers. The pendulum of enthusiasm to perform RT has shifted many times between "mandatory performance" to "do not perform" and to "selective performance." These swings reflect the continuously changing but deficient fund of knowledge of the cost–benefit relationship of the various triage policies for RT. This significant knowledge deficit emanates from two factors that exclude meaningful interpretation of the existing literature. First, many studies lack relevant information and use ambiguous nomenclature. For example, frequently there is no clear description of the indications, settings, and technique used. The physiologic state of the patient just prior to surgery is commonly not reported. Furthermore, the various authors commonly used pseudo-physiologic vaguely defined terms such as "no signs of life," "no vital signs," "lifeless," and "agonal." Lastly, many of the reports are selective and describe long-term inconsistent practices. These inconsistencies were recently confirmed by a survey that queried 304 members of the Eastern and American Associations for the Surgery of Trauma. This survey reported a lack of agreement regarding the indications for RT in multiple clinical scenarios as well as in defining "signs of life".(1) Second, the high-stress nature surrounding the care of moribund trauma victims presents a significant obstacle to the performance of high quality prospective studies.

Several factors were traditionally considered in the decision-making process for triaging patients for RT. These include the physiology of the patient at the scene and en route to the hospital, the time from injury and arrest, the mechanism and site of injury, and the status of the patient upon arrival to the trauma room. However, as pre-hospital information, including physiologic parameters and time lines, is often unreliable, inaccurate, or unavailable, many centers now focus on the injury mechanism (blunt vs. penetrating), site (thoracic vs. extra-thoracic) and physiologic status upon arrival only.

As there is no high-level evidence to support clear management guidelines for patients in extremis (see above), trauma centers across the country were obliged to develop individual paradigms. Although many elements of these individual protocols correlate, they also differ and emphasize various choices that frequently must be implemented based on specific clinical circumstances. This chapter describes algorithms for the management of the pulseless patient, which were used by the authors based on their experience as well as recent comprehensive reviews of the RT literature.(2–5) These protocols represent guidelines rather than dogmatic standard of care. Due to the complex nature of patients in extremis, not all victims fit into these protocols and good clinical judgment must always be applied.

INITIAL APPROACH

There are three initial treatment options when caring for a pulseless trauma patient. Within a few seconds or minutes, the surgeon must decide whether to perform RT, conduct a medical code, or pronounce the patient dead on arrival. As the arrival of such patients usually creates a high stress and sometimes chaotic situation, it is essential to establish management guidelines to assist the surgeon in selecting the right treatment option under such dire circumstances. To be effective, these guidelines must be simplified based on a minimal number of relevant clinical parameters. Since pre-hospital information is often unavailable or unreliable, it is impractical and unsafe to establish clinical pathways based on in-scene or in-transit reports. Thus, a growing number of trauma centers are now using triage protocols that are based solely on the mechanism and site of injury combined with two admission physiologic parameters, pulse and cardiac electrical activity. In addition to focusing the surgeon on salvageable patients, such protocols are useful because they allow the treating physician to instantly and reliably determine all essential parameters.

The mechanism and site of injury are established immediately by physical examination. The presence or absence of pulse is determined within seconds by palpating the most proximal pulse, the carotid pulse bilaterally. The patient's cardiac electrical activity is decided by applying the defibrillator palms on the patient's chest. It should be noted that some other triage protocols consider the patient's neurological status, as determined by the presence or absence of pupillary and/or corneal reflexes, spontaneous respiratory effort, and motor activity. However, as the neurological and respiratory status cannot be improved without restoring oxygen delivery to the brain and lungs, the determination of pulselessness and electrical activity can be exclusively used to both direct and simplify clinical decisions.

Patients in extremis arrive with a spectrum of clinical presentations. They may be in asystolic arrest or in pulseless electrical activity (PEA), which can be either organized or unorganized. They may arrive with profound hypotension, rapidly deteriorating blood pressure, or unobtainable blood pressure. There can be apneic or display agonal breathing. Finally, their initial neurological status may vary from moderately altered mental status to a deep coma with or without fixed dilated pupils or corneal reflexes. These parameters must be established within seconds after patient arrival, as time is critical and as each of these variables is central to the clinical decision-making process for the "near death" patient.

> In the case presented, no carotid pulse is palpable and cardiac monitoring shows asystole. The patient's down time is unknown.

DECISION-MAKING PROCESS

The decision-making process in managing trauma patients in extremis depends on the mechanism and site of injury as well as on the status of the patient's pulse and cardiac activity upon arrival. It is useful to classify several possible scenarios.

Patients Presenting with Measurable Blood Pressure, But Rapidly Deteriorate or Arrest

In this case, Advanced Trauma Life Support (ATLS) protocols are applied (6) and a primary survey is promptly performed. The airway is immediately controlled using in-line neck stabilization. Potential causes of the acutely worsening clinical condition such as tension pneumothorax, massive hemothorax, and pericardial tamponade are immediately identified and treated. Next, circulatory shock and the degree of the hemodynamic crisis are recognized, lines placed, and fluid and blood resuscitation is initiated. Upon rapid deterioration or arrest, more aggressive protocols are applied based on the mechanism of injury.

Penetrating Trauma—All patients with penetrating trauma who acutely deteriorate or arrest in-house should undergo RT (Figure 20.1). This drastic procedure presents the only hope to this group of patients. Furthermore, best outcomes following RT were reported in this group of patients, specifically in patients with penetrating thoracic trauma with cardiac tamponade.(4)

Blunt Trauma—Blunt trauma patients who acutely deteriorate or arrest in the trauma room should be managed more selectively

Penetrating, In-hospital pulse loss
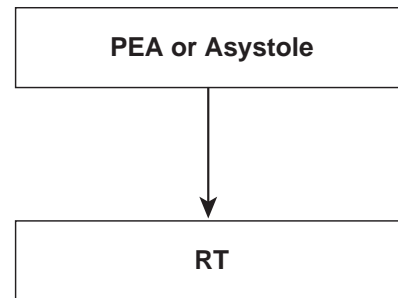
Figure 20.1 Algorithm for the management of penetrating trauma patients with in-hospital pulse loss. PEA, pulseless electrical activity; RT, resuscitative thoracotomy.

Blunt, In-hospital pules loss
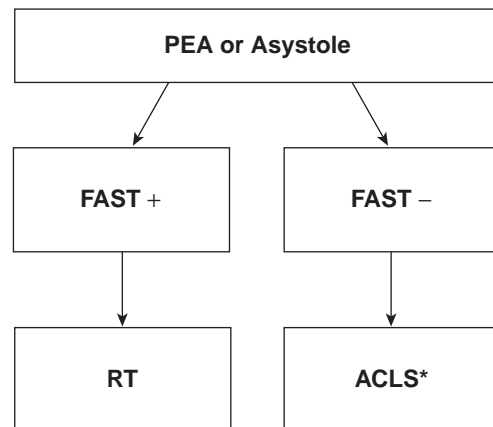
* Including bilateral chest tubes

Figure 20.2 Algorithm for the management of blunt trauma patients with in-hospital pulse loss. FAST+, pericardial effusion is present; FAST−, pericardial effusion is not present; RT, resuscitative thoracotomy; ACLS, advanced cardiac life support.

compared with penetrating trauma patients (Figure 20.2). This notion is based on two observations. First, survival following RT for blunt trauma patients in extremis is very low.(4, 5) Second, most of the rare survivors in this group of patients had cardiac tamponade. Thus, it is logical to perform RT only in blunt trauma patients who arrest because of cardiac tamponade. To that end, Focused Assessment of Sonography in Trauma (FAST) should be immediately performed in this group of patients to establish or exclude this condition. A FAST exam positive for cardiac tamponade should prompt RT while a negative study should direct the physician to perform advanced cardiac life support (ACLS)-guided resuscitation (7), including the insertion of bilateral chest tubes (in case there is tension pneumothorax). In the event that FAST is not available, the surgeon may opt to perform RT, hoping that the patient indeed has cardiac tamponade that can be drained.

Patients Presenting Pulseless

In these extreme cases only very expeditious and aggressive actions will alter outcome. Standard ATLS protocols (6) may be too slow to implement and deviations or alternative paradigms must be followed. On the other hand, there is a need to optimize resource utilization and prevent unnecessary exposure to blood born pathogens by excluding those patients who would not benefit from RT. To facilitate the decision whether to perform RT, conduct medical resuscitation, or pronounce the patient dead, it is recommended that immediately upon arrival the team should first establish pulselessness (palpating carotid pulse) and rhythm (applying defibrillator palms). Similar to patients who arrest in-house, the management of trauma victims with pre-hospital pulse loss depends on the mechanism of injury.

Penetrating Trauma–While most surgeons suggest that penetrating trauma patients who arrive pulseless but with PEA should undergo RT (8) (Figure 20.3), there is a debate regarding the management of those arriving asystolic. One school of thought suggests that RT should be abandoned in this group of patients. For example, a 1996 retrospective review of 80 asystolic patients (9) and a follow-up 1999 review of 28 additional patients (8) reported no survivors. In contrast, other surgeons suggest that RT should be performed in asystolic patients with penetrating trauma, especially when cardiac tamponade is suspected. This is based on a recent report of 26 survivors who underwent RT following pre-hospital CPR. Six of these patients, all with cardiac tamponade, arrived in asystole.(10) In line with the latter report, it is proposed that penetrating trauma patients who present in asystole should be managed selectively based on the presence or absence of cardiac tamponade (Figure 20.3). Practically, a FAST exam should be immediately performed and RT pursued if the study is positive for pericardial effusion. In the event that no effusion is identified, a medical resuscitation should be conducted. If FAST is not available, it seems reasonable to perform RT in patients with documented short (<5 min) down time and cardiac tamponade.

Blunt Trauma—Data derived from the initial enthusiastic and liberal use of RT for moribund trauma patients generated much skepticism regarding the efficacy of this procedure in blunt trauma patients. Indeed, the overall 1–2% survival rate reported for this group of patients (4) led a Subcommittee of the American College of Surgeons—Committee on Trauma to recommend in 2001 that RT be performed rarely in blunt traumatic arrest patients.(4) Furthermore, this Subcommittee recommended that RT should be limited to those arrive with vital signs at the trauma center and experience a witnessed arrest (see above). Thus, blunt trauma patients who present with pre-hospital loss of pulse and asystole should be pronounced dead and no resuscitation efforts should be pursued. However, as there are reports of survival following RT for blunt cardiac arrest secondary to cardiac tamponade, a more selective approach can be applied to this group of patients (Figure 20.4). In this case, a FAST examination is immediately performed if PEA is present and RT applied when pericardial effusion is noted. If FAST is not available, a medical code only should be pursued.

American College of Surgeons Recommendations

In an attempt to clarify the confusion surrounding RT, the American College of Surgeons Committee on Trauma (ACS COT)

Penetrating, Prehospital pulse loss
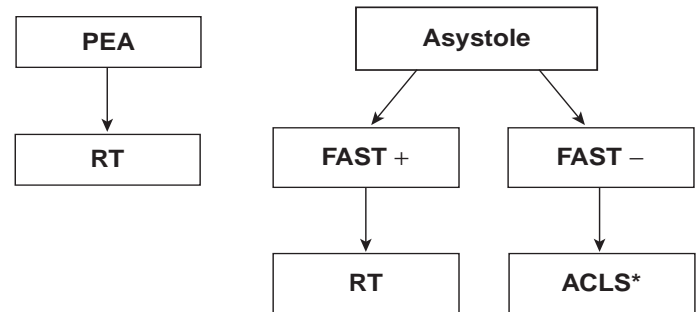
* Including bilateral chest tubes

Figure 20.3 Algorithm for the management of penetrating trauma patients with pre-hospital pulse loss. FAST+, pericardial effusion is present, FAST−, pericardial effusion is not present, RT, resuscitative thoracotomy, ACLS, Advanced Cardiac Life Support.

Blunt, Prehospital pulse loss
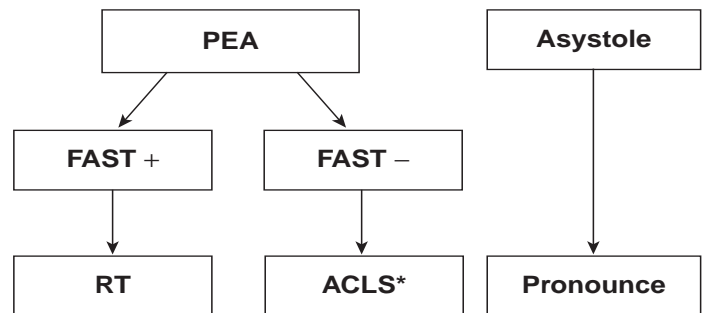
* Including bilateral chest tubes

Figure 20.4 Algorithm for the management of blunt trauma patients with pre-hospital pulse loss. FAST+, pericardial effusion is present; FAST−, pericardial effusion is not present; RT, resuscitative thoracotomy; ACLS, Advanced Cardiac Life Support.

presented practice management guidelines based upon an extensive meta-analysis of all relevant series published in the English literature between 1966 and 1999.(4) After a careful exclusion process, this meta-analysis reviewed 42 series of emergency thoracotomy applied to general trauma patients, 46 papers dealing with cardiac injuries, and 4 reports on pediatric patients. As ethical factors prevent a prospective randomized investigation of this topic, the ACS COT, as expected, could not identify evidence to support Level I (scoring system not mentioned) recommendations for RT practice guidelines. Nevertheless, the Committee identified the following recommendations based on Level II data:

1. RT should be performed rarely in blunt trauma patients with cardiopulmonary arrest because of the very poor outcome of this group. The procedure should be reserved to those blunt trauma patients who have an in-house arrest.

2. RT is best applied to patients sustaining penetrating cardiac injuries who arrive after a short pre-hospital time and have witnessed or measured signs of life (pupillary response, spontaneous ventilation, presence of carotid pulse, measurable or palpable blood pressure, extremity movement, and cardiac electrical activity).

3. RT should be performed in patients with non-cardiac thoracic injuries although survival is low. As it is impossible to ascertain in advance whether chest injuries are cardiac or non-cardiac, RT should be performed to establish the diagnosis.

4. RT should be performed in a selected group of patients sustaining exsanguinating abdominal vascular injuries as an adjunct to definitive repair of the injury. Survival in this group of trauma victims is low.

5. The above guidelines should be applied also to the pediatric population.

> In the case presented, a FAST examination is performed immediately after establishing pulselessness and asystole, and a pericardial effusion is noted. Thus, it is decided to perform a RT. It should be noted that the presence of PEA rather than asystole would have prompted RT without performing a FAST examination.

RESUSCITATIVE THORACOTOMY

RT is a very aggressive procedure, which provides the only hope for survival to a selected group of trauma patients in extremis. The procedure aims to prioritize cerebral and coronary perfusion by establishing pump function through open cardiac massage and diversion of blood by cross-clamping of the descending thoracic aorta. In addition, the exposure obtained via RT enables the surgeon to address almost all immediate intra-thoracic life-threatening injuries including cardiac tamponade and exsanguinating pulmonary, cardiac, and major vessel lacerations. Occasionally, RT may provide the critical time required for control of extra-thoracic injuries.

Historical Overview

RT evolved largely by trial and error. The literature regarding this procedure is plagued with poor study design, ambiguous nomenclature, and selective reporting practices. Consequently, although RT was performed for decades with similar techniques, the indications for this procedure varied and practice trends were established without a solid cost–benefit analysis. The first repair of penetrating cardiac injury was reported in 1897 (11) and the first successful resuscitation of a cardiac arrest victim was published 4 years later.(12) During the following six decades thoracotomy was widely employed for the treatment of cardiac arrest although it is not clear whether these procedures were the equivalent of the modern operation. In addition, the number of truly resuscitative thoracotomies performed during this period and their outcome is impossible to determine. In the 1960s and 1970s, advances in life-support systems and cardiac surgery led to liberalization of the indications for RT. Furthermore, encouraging data, almost all from patients with penetrating cardiac wounds, triggered a widespread application of RT for almost all patients in extremis. The efficacy of resuscitative thoracotomy especially in blunt trauma patients and in victims with penetrating non-cardiac injuries was severely questioned in the 1980s. During that period, many studies demonstrated very poor outcomes when RT was used liberally. These data combined with the rising incidence of HIV and hepatitis caused the pendulum of RT to shift toward a highly selective approach, as described previously in this chapter.

Logistics

RT can be performed in the trauma room, operating room, or intensive care unit. Regardless of the specific location, it is critical that the space where RT is performed be well arranged and equipped to address the basic logistical requirements for performing this procedure. First, the room must be large enough to comfortably accommodate the many team members involved. Second, the patient should be placed on a bed or a stretcher whose height can be adjusted. Third, the room must be well lighted and contain all the basic supplies and equipment for performing RT including rapid infusers and fluid warmers. Most importantly, it is essential that a prearranged surgical tray containing all the necessary equipment for RT (Figure 20.5) be stored at all times in the room.

Who Should Perform RT?

This question has been considerably debated, especially in the context of hospitals where a surgeon is not immediately available. In some of these institutions, Emergency Medicine physicians or trained pre-hospital providers perform this procedure. (13) The supporters of this policy suggest that some patients who otherwise would have not survived can be saved. On the other hand, opponents of this approach argue that RT should be performed only by an experienced surgeon who is able to address the various surgical scenarios required to control intrathoracic exsanguination.

Technique

RT is performed while the patient is in a supine position with both arms extended. A left anterolateral incision is made at the level of the fourth intercostal space from the lateral border of the sternum to the midaxillary line in a slight upward curve. In the male, the nipple could serve as a good landmark under which the incision is made. In females, one can use the sternal angle to mark the second intercostal space, and then count two intercostal spaces down just lateral to the sternum to identify the starting point of the incision. Alternatively, the breast can be retracted in a cephalad direction, and the incision made along the inframammary fold.

As opening the chest is performed boldly, it is safer to cut the subcutaneous layer and muscles (pectoralis and serratus) over the rib rather then in the intercostal plane. This minimizes the risk for injuring the lung or the intercostal bundle. The pleura is identified and opened with a knife. At this point, a finger or two should be inserted and the intercostal space is opened using electrocautery, heavy scissors, or sheer manual force. Once the intercostal window

Figure 20.5 A thoracotomy surgical set. Please note that the set has two trays. The top one (A) contains mainly sterile towels and laparotomy pads, whereas the bottom one (B, C) contains the surgical instruments and defibrillator paddles.

identify and drain cardiac tamponade, and resume hemodynamic function. To that end, a quick but thorough exploration of the thoracic cavity and mediastinum is performed after evacuating fresh or clotted blood and after mobilizing the lung cranially by hand or by a lung retractor. Frequently, this maneuver cannot be done without first dividing the inferior pulmonary ligament with special care not to injure the inferior pulmonary vein. Following the thoracic cavity exploration, the surgeon should be able to establish whether to proceed with bleeding control or discontinue any efforts if massive and unreconstructable injuries are present.

Control of Injures

Cardiac tamponade: If violation of the pericardium or blood in the pericardial space is identified, the next step is to widely open the pericardium. This is performed by carefully incising the pericardium longitudinally just anterior to the phrenic nerve. If the pericardium is not distended, it is important not to lacerate the heart when opening the pericardial sac. Thus, it is recommended that the pericardium be grasped with a forceps or clamp and only then opened with a knife. When tamponade is present, the pericardium is frequently tensed, firm, and unyielding to grasping. Under such circumstances, the heart is protected by the pericardial layer of blood, and therefore the pericardium can be safely opened by making a small incision with a knife. For better protection, it is possible to tent the pericardium using a superficial 3–0 silk stitch before using the knife. Regardless of whether the pericardiotomy is done for release of cardiac tamponade and repair of a cardiac wound or for cardiac massage, the pericardial sac must be opened as wide as possible in order to deliver the heart without compressing its base.

Cardiac injuries: To thoroughly explore the heart it must be delivered out of the pericardial sac, as described above. Upon delivering of the heart, the surgeon often needs to deal with potentially conflicting scenarios. On the one hand, brisk bleeding from cardiac lacerations may be encountered and control of all bleeding sites is the utmost priority. On the other hand, excessive traction required for exploration and control of bleeding may lead to cardiac arrest in patients whose heart is still pumping. Thus, inspection and manipulation of the heart must be done very gently.

Small easily accessible cardiac lacerations are temporarily controlled by digital pressure and repaired with several pledgeted sutures while the finger is in the occluding position. Bleeding from larger lacerations can be controlled using several techniques. If the wound is finger breadth, control by placing a finger inside the hole should be attempted. Cardiac wounds that cannot be controlled by digital occlusion can be temporarily occluded by gentle traction of an inflated Foley catheter balloon placed within the heart. When performing this maneuver care must be taken not to increase the wound size, as the cardiac muscle may be edematous and friable due to massive fluid resuscitation. The placement of skin staples became a very popular method for controlling large linear lacerations. This useful technique is not considered permanent and the staples must be replaced or reinforced with pledgeted sutures during a definitive operation if the patient survives the RT. Finally, gaining control of large open cardiac wounds can be achieved

is sufficiently open, a Finochieto rib spreader is placed and used to widen the exposure as much as possible, even at the expense of fracturing ribs. It is important to remember that the rib spreader should be applied with its ratchet bar laterally to enable extension of the thoracotomy incision to the contralateral side if needed.

Once the thoracic window is maximally widened, the immediate needs are to locate and control sources of massive bleeding,

by sewing the defect with wide, criss-crossing, horizontal mattress sutures. This procedure is particularly efficacious in non-pumping or fibrillating hearts when bleeding may not be brisk. In the pumping heart, traction across the wound may minimize bleeding and allow completion of the repair.

The management of posterior cardiac lacerations, seen mostly with gunshot wounds, could be extremely challenging. Exposure through a left anterior thoracotomy is often impossible, and therefore trans-sternal extension of the incision to the right chest is frequently required while digital pressure is applied to temporarily control bleeding. Posterior wounds are also difficult to manage because they require lifting of the heart, a maneuver frequently not tolerated by the patient. Elevation of the heart can be done either by applying a Satinsky clamp to the acute anterior margin of the right ventricle or by placing a doubly passed, deep stitch through the cardiac apex muscle.

Patients with wounds involving massive myocardial destruction or large valvular or septal injuries rarely survive RT. The few reported survivors were all placed on complete cardiopulmonary bypass for repair of their extensive injuries. Transection of a main coronary artery leads to severe cardiac ischemia usually incompatible with survival to reach the hospital.(14) The most common coronary artery injury in patients who arrive to the hospital in extremis is transection of the distal LAD artery. In this case, ligation of the distal one-third of the artery may be life saving although infarction in the territory of this vessel as well as arrhythmias is inevitable. Managing a lateral laceration of a proximal main coronary artery presents a major management dilemma. The surgeon needs to deal with a profusely bleeding vessel that cannot be ligated for fear of a major myocardial infarction or cardiac arrest. The only hope for these patients is repair under full cardiopulmonary bypass while the artery is temporarily control by digital pressure.

Thoracic vascular injuries: A detailed description of the management of major thoracic vessel injuries is beyond the scope of this chapter. Nevertheless, several principles for emergent control of these injuries should be emphasized. First, most patients with thoracic great vessel injury do not make it alive to the hospital. Those who do survive the transfer arrive in extremis unless tamponade through pseudoaneurysm formation has occurred. Second, these patients are best served by immediate RT or vascular control. Third, as soon as a great vessel injury or a transmediastinal wounds is suspected while performing a left anterolateral RT, bilateral thoracotomy should be immediately pursued. This saves precious seconds and provides excellent exposure to the aorta and to all branches emanating from the arch. Fourth, dissection of injured vessels for proximal and distal control when the patient is exsanguinating should not be pursued, as they are liable to result in cardiac arrest. Instead, manual control should be attempted and fluid and blood resuscitation be initiated. If manual pressure is ineffective or prevents cardiac massage, a proximal partial clamping of the injured vessel may be required. Fifth, if manual control and fluid resuscitation have been established, the surgeon must decide whether to continue with a clamp control of the injured vessel in the Emergency Room or in the Operating Room. Sixth, the specific injured vessel must be exposed through quick dissection for obtaining a proximal control.

Venous injuries are an uncommon indication for RT. This is because most of these injuries spontaneously tamponade and seal due of their low intraluminal pressure and as a result of their mediastinal and subpleural location. Thus, most venous injuries are treated when addressing adjacent arterial wounds. The most significant injuries are those involving the superior and inferior vena cava. Both vessels can be injured either within or outside of the bound of the pericardium. Every attempt should be made to repair these vessels, as ligation of the SVC invariably leads to severe brain edema and neurological dysfunction, while ligation of the intrapericardial IVC dramatically reduces venous return and results in cardiac arrest. Both the innominate and the subclavian veins as well as the azygos vein can be ligated if repair is not feasible. It should be noted that the risk for air embolism is high in the presence of venous injuries and that this risk may increase by manipulating the vessel for control of bleeding and repair.

Hilar and proximal lung injuries: Hilar and medial lung injuries can be catastrophic. The usual presentation is cardiovascular collapse secondary to exsanguination (pulmonary artery or vein injury), massive air embolism (bronchovascular fistula), and/or tension pneumothorax (bronchial or lung injury). Control of the hilum is always the first management priority once a hilar wound is identified. This is obtained by incising the inferior pulmonary ligament and opening the pleura all the way up to the inferior aspect of the hilum. Care must be exercised not to injure the inferior pulmonary vein, which is the most caudal structure in the hilum. Once the hilum is exposed, the surgeon can either twist the hilum 360° or apply a vascular cross-clamp it. Both maneuvers can be facilitated if ventilation is transiently discontinued, and coordination with the anesthesiology team is critical to the success of this effort. Acute obstruction of the hilum has profound physiological consequences, which frequently cannot be tolerated by the hypothermic, acidotic, and coagulopathic patient. Most importantly, hilar clamping forces the entire cardiac output to flow through the constricted contralateral lung vasculature. This triggers acute massive right-side heart failure, which is extremely difficult to treat. Sometimes, only expeditious application of the clamp to the lobar level may save the patient.

Extra-thoracic injuries: Extensive meta-analysis by an ad hoc committee of the American College of Surgeons concluded in 2001 that RT should be performed in moribund patients with exsanguinating abdominal vascular injuries although survival rate is low.(4) This recommendation is supported by two recent retrospective reviews of patients with extra-thoracic penetrating injuries. In one study, 8 out of 50 patients (16%) who underwent pre-laparotomy RT for major abdominal exsanguination survived neurologically intact.(15) In the second review, survival rate in a group of 27 patients who underwent RT for non-torso injuries was 11%.(16)

RT is used in this group of patients mainly for cardiac resuscitation and for decreasing downstream bleeding. If the patient responds to the RT, focus should shift to addressing the extra-thoracic life-threatening injury. In the case of abdominal vascular injury, laparotomy should be pursued and the thoracic aortic clamp must be removed as soon as possible and placed where appropriate below the diaphragm.

Aortic Cross-Clamping

As described above, aortic cross-clamping is an important component of RT. This maneuver diverts blood to sustain the cerebral and coronary circulation while reducing downstream bleeding. Ideally, aortic clamp placement should be done only after good exposure and clear vision are obtained. However, in the pulseless trauma patient, this procedure may be very difficult. This is because the descending aorta is flaccid and cannot be palpated, and since exposure is often severely compromised by a large mediastinal hematoma and by the cyclically inflated lung. Thus, aortic clamping in RT is guided mainly by knowing where the descending aorta anatomically lies. The most helpful markers are the thoracic vetebral bodies that are positioned just posteriorly to the aorta. To locate the aorta, the surgeon must identify these easily-palpable boney structures and open the pleura anteriorly.

As clamps applied on the aorta through intact pleura often fail to hold securely, it is essential to open the parietal pleura above the aorta. Extensive dissection to provide exposure is laborious and time consuming and should be avoided. The pleura should be opened anterior and posterior to the aorta at the site of intended occlusion just to allow the passage of the jaws of the clamp. These are passed through the pleural holes and securely closed over the entire circumference of the aorta. Care should be taken not to erroneously cross-clamp the esophagus, which lies in close relationship medially to the aorta. If time permits, insertion of an orogastric tube can help avoiding this complication.

Blood pressure response to aortic cross-claming can be used as a crude prognostic sign. Many surgeons consider the failure to elevate systolic blood pressure above the aortic clamp beyond 70 mmHg as an ominous prognostic sign and as indication for terminating the RT.(17) On the other hand, excessive blood pressure elevation above the aortic clamp may indicate that the left ventricle is pumping blood against a significant afterload. This event can be exacerbated when epinephrine or other inotropic drugs are used. When the aortic clamp is placed for extra-thoracic bleeding, premature de-clamping may result in precipitous blood pressure drop and exsanguination. In this case, it is prudent to ignore the hypertension and leave the clamp in place until bleeding is controlled. When cross-clamping is done for proximal aortic or cardiac injury, proximal hypertension may increase blood loss and slow down repair attempts. Under such circumstances, declamping is immediately indicated.

Resuscitation

Open cardiac massage: Cardiac massage is performed when the heart is standstill, severely bradycardic, or in the presence of ventricular fibrillation. In the trauma settings, these conditions most commonly result from severe hypoxia, profound loss of effective blood volume, cardiac tamponade, or air embolism. Thus, for cardiac massage to be effective, attempts to address the underline cause(s) must be pursued in parallel.

Cardiac massage aims to resume pump function and circulatory flow. This procedure can be efficacious only if the heart is completely delivered out of the pericardial sac (see above), if sufficient intravascular volume is restored (see below), and if the descending thoracic aorta is cross-clamped (see above). Optimally, massage is performed with two hands. In this technique, the slightly cupped hands of the operator are placed on the anterior and posterior surfaces of the heart and the ventricles are compressed from the apex toward the aortic root at a rate of approximately 60 beats per minute. When massaging the heart, the operator should avoid two important pitfalls. First, iatrogenic injury to the heart can occur if the fingers are not placed flush on the epicardial surface. Second, venous inflow can be impeded if the heart is placed under traction.

Intra-cardiac drug administration: As the heart is exposed during RT, intracardiac administration of resuscitation drugs is possible. The most commonly administered drug is Epinephrine. This drug is injected into the left ventricle to avoid passage of the administered bolus through the pulmonary circulation where it induces acute pulmonary hypertension that impedes cardiac output during cardiac massage. Other resuscitation drugs such as bicarbonate and calcium can be administered directly into the heart although there is no evidence to support their efficacy. Thus, many surgeons prefer to administer drugs other than epinephrine intravenously only.

Drug administration into the left ventricle is done through the apex of the heart while avoiding major coronary arteries. To minimize bleeding from the injection site, it is essential to use a thin needle (22 gauge). Also, blood must always be aspirated before drug injection to avoid intramyocardial injection of epinephrine or other drugs, as this may induce severe intractable arrhythmias.

Open cardioversion: As the resuscitation progresses, it is possible that the heart may develop coarse ventricular fibrillation. To best address this arrhythmia, internal, direct cardioversion should be attempted. To that end, internal cardiac paddles, supplied in the RT set (Figure 20.3), are applied firmly to the anterior and posterior walls of the heart and 10–30J is discharged. Frequently, restoration of supraventricular rhythm is insufficient to support adequate perfusion, and inotropic agents, aortic cross-clamping, and cardiac massage should be continued.

Venous access: Occasionally, it is very difficult or even impossible to insert large bore intravenous lines in patients presenting with profound shock or arrest. In this situation, fluid administration must be carried out directly into the heart. This is done by inserting a high caliber line such as a Foley catheter through a purse-string suture into the right atrial appendage. It is critical to infuse only warm fluids and warm blood products through this line, as acute cardiac hypothermia may trigger arrhythmias and arrest.

OTHER ISSUES

Right, left, or mid-sternotomy? RT for the patient in extremis is almost always performed on the left because it allows the quickest entry into the chest and access to open cardiac massage, cross-clamping of the aorta, and most cardiac injuries, In contrast, RT through a right anterolateral thoracotomy is more time consuming, as the azygos vein needs to be mobilized or severed. Furthermore, open cardiac massage and cross-clamping of the aorta are difficult and sometimes impossible via this incision. Nevertheless, this approach can be applied for control of vascular or hilar injuries in relatively stable patients.

Although midsternotomy is the preferred elective incision for approaching the superior mediastinum and right thoracic outlet,

it is rarely performed in moribund patients. The time necessary to carry out this incision and the restricted access it provides to the posterior mediastinum and aorta limit its use in these settings. Nevertheless, mid-sternotomy can be considered in patients with a previous left thoracotomy.

There are two management options for patients in extremis who sustained a transmediastinal penetration or with suspected right-side major vascular injury. First, it is possible to initially perform a left anterolateral thoracotomy for open cardiac massage, aortic cross-clamping, and manual control of bleeding. If this procedure suggests right-side life-threatening pathology or if there are no significant left side injuries, the surgeon should extend the thoracotomy incision across the sternum to the right chest. An alternative option could be the performance of bilateral trans-sternal thoracotomy as the initial incision.

Air embolism: The presence of air bubbles in the coronary or cerebral circulation has catastrophic consequences including obstructive myocardial and brain infarcts that lead to profound neurological and hemodynamic collapse and death.(18) This condition occurs when air enters the systemic or pulmonary circulation via lacerated major vessels, cardiac wounds, and/or severely contused lungs. Moribund trauma patients undergoing RT have an excellent platform for this complication to occur. First, most of these patients have severe intra-thoracic injuries involving lacerated vessels, heart, or lungs. Second, the pulmonary venous pressure of these patients is very low due to their massive blood loss. Third, positive airway ventilation is applied to all patients. Fourth, some of the procedures employed in RT including placement of a right atrial catheter and repair of cardiac lacerations inevitably result in air embolism.

The diagnosis of air embolism in the acute settings of RT is very difficult. Acute decompensation, the hallmark of air embolism, can be related to multiple other etiologies including cardiac ischemia, hypothermia, acidosis, and severe hypovolemia. Thus, unless air bubbles are seen in the coronary arteries or heart chambers, this diagnosis cannot be established in RT patients. However, since the potential for this complication is very high, it is prudent to assume that all patients undergoing RT have some degree of air embolism. Consequently, routine aspiration of air from the aortic root and the left ventricle (after tilting the patient to the right) at the completion of thoracotomy is strongly recommended.

Termination

For those patients who survive RT, the completion of this procedure is usually marked by their transfer to the operating room for a definitive control of injuries. However, the decision whether to transfer the patient to the operating room or to discontinue the RT is complicated and based almost exclusively on surgical considerations of difficult to define parameters. Is the cardiac activity sustainable? Is the blood pressure maintainable? Is the injury repairable? Are the coagulopathy, acidosis, and hypothermia correctable? Unfortunately, there are no solid data to assist the surgeon in this intraoperative triage decision making. Some surgeons suggest that RT should be terminated if systolic blood pressure remains below 70 mmHg despite aortic occlusion for more than 30 minutes.(17) Others suggest that severe

post-de-clamping hypotension in spite of maximal resuscitative efforts ("de-clamp shock") can be used as another indicator for terminating the operation.

In the presented case, the patient is intubated using RSI and a left anterolateral thoracotomy performed. In parallel, to address a potential right tension pneumothorax, a chest tube is inserted into the right chest. However, there is no return of air or blood. In addition, two large bore intravenous lines are placed into the right subclavian and right femoral vein, respectively. Upon opening the chest, approximately 500 ml of fresh and clotted blood are identified and evacuated. A 2-cm pericardial laceration is noted through which blood is spurting. The pericardial sac is purple-grey and very tense. The diagnosis of cardiac tamponade is made and the pericardium is longitudinally opened anterior to the phrenic nerve. No cardiac activity is noted and approximately 50 ml of fresh blood are drained. Upon further exploration, a 1 cm bleeding laceration is observed in the right ventricle. About 1 minute after opening the pericardial sac and after one dose of epinephrine, the patient's heart regains spontaneous function and systolic blood pressure recovers to 80 mmHg. Bleeding is temporarily controlled by digital pressure and the wound repaired using two pledgeted 3-0 Prolene stitches. After receiving 4 l of lactated Ringer's solution and 1 unit of O Rh$^+$ blood, the patient's systolic blood pressure increases to 100 mmHg and his pulse is 110 bpm. At that point, the chest cavity is thoroughly irrigated and the thoracotomy incision is closed after placing a single chest tube. The patient is transferred to the SICU with stable vital signs.

On post-operative day 2 the patient is extubated and the chest tube discontinued. One day later, the patient develops fever and his heart rate increases to 130 bpm. Chest radiograph demonstrates a new left lower lobe infiltrate and his white count is 17,000. Antibiotic treatment is initiated for pneumonia. On post-operative day 7 the patient is discharged.

Massive Transfusion

Acute massive blood loss is a major cause of death in trauma patients and blood replacement in the exsanguinating patient is a significant clinical and logistical endeavor. Special protocols for massive blood transfusion must be established and activated based upon clear guidelines. It is critical that these protocols be executed efficiently upon activation and that the concept of "no questions asked" is strictly applied. The failure to execute such protocols may result in sub-optimal resuscitation in which tissue hypoperfusion, hypothermia, coagulopathy, and acidosis compromise the patient's ability to survive even after bleeding is controlled.

Massive blood transfusion is now recognized as a distinct clinical entity that requires extensive investigation. Although a variety of protocols are applied in different trauma centers, there are several common characteristics:

1. As time is critical, resuscitation starts immediately without typing and cross matching and using the universal donor blood type O. As O Rh⁻ blood type is relatively uncommon, some centers use a selective paradigm: Females of childbearing age are resuscitated with O Rh⁻ packed red blood cells while all other patients are given O Rh⁺ blood type. To prevent any delays, many trauma centers store refrigerated blood in their trauma bays.
2. Clotting factors must be provided together with red blood cells transfusion. Early practice involved the administration of a unit of FFP for every 4–5 units of blood. Later studies have shown that no FFP is needed unless more than 10 units of blood are given. More recently, there is an accumulating body of literature, especially based upon military experience, in support of 1:1 blood to FFP ratio resuscitation.(19)
3. Platelets are given to minimize or correct coagulopathy. Typically, one unit of single donor platelet is administered with every 8–10 unites of blood. Although this practice has gained much popularity, there is no clear evidence that correlates shock outcome with platelet counts.
4. Recombinant activated factor VII (rFVIIa) is more frequently used for controlling massive traumatic blood loss or for containing traumatic brain injury in coagulopathic patients.(20)

Damage Control

Damage control approach is the natural continuation of RT. This concept, which can be applied to thoracic, abdominal, vascular, and orthopedic injuries, aims to quickly control bleeding and contamination without performing definitive, time-consuming repairs. After the initial life-saving intervention, the patient is taken to the intensive care unit for further resuscitation. When the patient has been appropriately stabilized, usually within 12–72 h, definitive repairs are performed. This paradigm addresses the major enemies of the trauma patient: bleeding, contamination, hypothermia, coagulopathy and acidosis, and allows many patients deemed unsalvageable to survive.

A detailed discussion of this very intriguing strategy is beyond the scope of this chapter and a comprehensive review of this topic is presented somewhere else in this book.

Quality of Evidence

Evaluating the results of RT is very difficult. The overwhelming majority of the reports are retrospective, and many centers presented overlapping studies or experience stretched over several decades. Definitions of "signs of life" and "vital signs" are varied and often unclear. Statistical analysis and outcome-oriented physiological parameters are very rarely reported.

In the past 10 years, several publications attempted to decode the voluminous RT data and to present consensus guidelines.(1–5) In spite of the inherent difficulties described above, these reviews were able to identify several conclusions based on low level but consistent evidence. These conclusions provided the foundation for the paradigms presented in this chapter although some modifications were made for usage in Level I and Level II trauma centers where a trauma surgeon is immediately available. The main conclusions of the review articles are:

1. There is evidence to support *not performing* RT thoracotomy if vital signs or signs of life were never present after injury (1C).
2. There is evidence to support *performing* RT if there is a documented in-hospital loss of vital signs or signs of life (1C). This is especially emphasized in patients with penetrating chest trauma (1C). In blunt mechanism of injury, there is some evidence that RT is more beneficial in patients with cardiac tamponade (2B).
3. There is evidence to support *not performing* RT in blunt trauma patients with pre-hospital loss of initially present vital signs or signs of life (1C). The one exception could be patients with cardiac tamponade (2B).
4. There is evidence to support *performing* RT in penetrating trauma patients with pre-hospital loss of initially present vital signs or signs of life (1C). This is especially relevant to patients with penetrating cardiac injuries and tamponade (1C).

Grading was done based on the GRADE classification developed by the American College of Chest Physicians.(21)

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21 Related blast injury

Gidon Almogy, Howard Belzberg, and Avraham I Rivkind

A 19-year-old female is seating in a restaurant when a suicide bomber detonates an 8 kg improvised explosive device. Her father and sister are killed immediately, her mother seriously injured. She is extricated from the restaurant by passers-by, awake, and complaining of tinnitus. Initial evaluation by EMS personnel reveals multiple penetrating wounds and burns. She is transferred to the closest level I trauma center.

She is met by the surgeon-in-charge at the ambulance bay and based upon the multiplicity of injures she is triaged to the Trauma Room. In the Trauma Room she is awake, complaining of tinnitus and constantly inquiring about of mother and sister. Primary survey reveals an intact airway, decreased breath sounds bilaterally, oxygen saturation 90% with a face mask, pulse 120 bpm and systolic blood pressure 105 mmHg. On secondary survey there are multiple penetrating wounds in her face, eyes, chest, abdomen and lower extremities. Her abdomen is soft, non-distended, and without signs of peritonitis. There are second degree burns over her forearms, neck, and face covering 10% of her body surface area (BSA). Otoscopic examination reveals bilateral tympanic membrane rupture.

Bilateral #32 chest tubes are inserted and Ringer s lactate solution as well as broad-spectrum antibiotics are administered via two large-bore ante-cubital intravenous lines. Focused abdominal sonography for trauma (FAST) detects a small amount of peritoneal fluid. A chest X-ray demonstrates no pneumothorax or hemothorax, opacities over both lung fields, and well-positioned bilateral chest tubes. Her hemodynamic status improves (BP 110/70 mmHg, pulse 98 bpm). A Foley catheter and a nasogastric tube are inserted, and the patient is taken to the CT scanner.

Pan-CT is performed. There are penetrating missiles in the scalp, consistent with bomb-related shrapnel, but no intra-cranial injury. Shrapnel is detected in the left chest wall and there are bilateral pulmonary contusions, consistent with blast lung injury (BLI). In the abdomen there is a moderate amount of free peritoneal fluid and a suspected small bowel injury.

The patient is transferred from the CT scan to the operating room. Laparotomy performed through a midline incision identifies a moderate amount of enteric contents and lacerations in two segments of small bowel. These segments are resected, and a primary anastomosis is fashioned. The abdomen is copiously irrigated and closed primarily. Next, the burns are gently debrided with gauze and an antimicrobial solution is applied.

She is brought intubated to the surgical ICU. Radiographic and clinical findings of pulmonary contusion improve gradually within 48 h and the patient is extubated on the fourth hospital day. On the eighth post-admission day, she develops fever and erythema of her miline abdominal wound. The wound is partially opened and drained. Her fever resolves and she is transferred to the floor on the 13th post-admission day. She gradually tolerates diet and physiotherapy is started. On the 18th day post-admission she is transferred to a rehabilitation facility.

WHAT ARE THE MECHANISMS OF INJURY FOLLOWING SUICIDE BOMBING ATTACKS?

Trauma following explosions has traditionally been classified into primary, secondary tertiary, and quaternary injury (1A).(1) Primary blast injury occurs as a direct effect of changes in atmospheric pressure caused by the blast wave. Injury to gas-containing organs such as perforation of the middle ear (22.1%) and BLI (18.2%) are most common (1A).(2) Secondary blast injury is caused by shrapnel and debris that are propelled by the blast. Compared to high-velocity firearms, shrapnel travel at lower velocity (800–1,000 m/sec vs. 300–400 m/sec, respectively), and thus the energy each particle contains is lower. The damage each particle inflicts depends on its mass, distance from explosive device, and ballistic shape (1B).(3) Tertiary blast injury includes injury from collapsing buildings and from a victim s body being displaced by expanding gasses and high winds; trauma then occurs from tumbling and impacting objects and displacement of the victims (2C).(4) Burns, crush injury, and associated injuries such as inhalation of dust, smoke, and other chemicals are termed quaternary injuries.

In the presented case the patient sustained severe primary, secondary, and quaternary injuries, suggesting proximity to the explosive device. The combination of such injuries should raise the suspicion of sustaining severe injuries.

WHAT ARE THE EXPECTED TYPES OF INJURIES FOLLOWING SUICIDE BOMBING ATTACKS?

Victims of terrorist explosions are more severely injured than victims of other types of trauma. The rate of severe injuries, i.e., injury severity score (ISS) ≥16, is 28.7% in the terror group compared with 10% for all other types of trauma (1A).(5) In addition, the need for abdominal, vascular, and neurosurgical procedures is higher among terror-related victims. The extent of injuries is also more severe and more complex compared with victims of other forms of trauma. Effects of the blast and heat waves, and multiple penetrating injuries, are common among victims and are the hallmark of such attacks. This phenomenon when different classes of injury occur simultaneously in the same patient is termed multidimensional injury pattern (1B).(6)

Penetrating injuries caused by gunshot wounds are most often limited to one or two body regions. Penetrating injuries caused by the detonation of an explosive device carried by a suicide bomber are widespread and cover a large surface area. Each particle may cause less damage than gunshot wound (GSW), but the multiplicity of particles causes diffuse tissue damage. Survivors suffer a combination of penetrating wounds of varying severity and location. The extent and severity of injury will depend on factors such as the explosive power of the device, distance of the victim from site of detonation, quantity and mass of shrapnel, and attack setting.

DOES ATTACK SETTING HAVE IMPLICATIONS ON INJURY?

The distribution of primary, secondary, tertiary, and quaternary blast injury is also determined by the physical characteristics of the attack setting. Buses, restaurants, and indoor cafés are defined as confined spaces, while outdoor cafés, bus stops, and open markets are defined as open spaces (1A).(7) In confined spaces the blast and heat waves are reflected off the walls and are thus propagated. In open spaces the blast wave dissipates with the distance from the explosive device. Attacks perpetrated inside confined spaces have caused an overall greater number of casualties per attack and a greater number of severely injured casualties (ISS ≥ 16) per attack compared with attacks in open spaces (1A).(8) For example, the median number of victims admitted to the ER following explosions in a confined space was 11 compared with 5 victims in an open space.

Explosions inside confined spaces such as the interior of a bus or inside a restaurant result in significantly higher mortality rates compared with similar explosions in open spaces (49.5% vs. 7.8%, $p < 0.0001$) (1A).(9) These differences are attributed to reflection of the blast wave in confined spaces and the relatively shorter distance between the victims and the explosive device. The incidence of moderate and severe BLI in confined spaces is also significantly higher compared to open spaces (81.8% vs. 33%, $p < 0.05$) (1A).(10)

In all settings, the head sustains more penetrating wounds than any other body part (1A).(11) Penetrating head injury is more common among victims aboard buses (68.1%), penetrating torso injury more common in restaurants (58.7%), and penetrating extremity injury is more common in open spaces (66.7%). Victims in open space attacks are less likely to suffer from the effects of the blast wave (burns and tympanic membrane rupture) compared to patients injured in confined spaces. A meta-analysis of 29 worldwide terrorist bombing attacks showed that the incidence of burns and tympanic membrane rupture inside a confined space was 22 and 35%, respectively, compared to 1 and 5%, respectively, in an open space (2A).(12)

> In the presented case the victim was injured inside a restaurant, a confined space. Thus, the range of expected injuries should be BLI, multiple penetrating injuries, burns, and tympanic membrane rupture.

WHAT SHOULD BE PERFORMED AT THE SCENE BY EMS CREWS AND WHERE SHOULD VICTIMS BE TAKEN?

The grotesque sight of the inside of a restaurant following a terrorist attack is numbing and shocking. In these chaotic circumstances, it is imperative to quickly establish command and control. The scene must be quickly surveyed and evaluated, and the location and condition of the seriously injured must be identified. Hospital response depends largely on initial reports from the scene which need to be as accurate as possible. Information including scene setting and the number of seriously injured victims are pivotal to estimate the scale of the attack. The number of lying wounded serves EMS crews as a surrogate for the number of seriously injured victims.

Victims are divided into those with life-threatening injuries (urgent) and those without such injuries (non-urgent). Urgent victims are stabilized and evacuated. Only immediate life-saving procedures, such as needle application, oro-tracheal intubation, and control of massive external bleeding, are performed by EMS crews (scoop and run) (1A).(13) Utilizing this approach, evacuation times in Israel have been vary short and range from 5–10 minutes in urban areas to 15–20 minutes in rural areas (2A).(14)

Controversy exists as to where should victims be evacuated following multiple casualty incidents such as terrorist bombing attacks. Data from Israel demonstrates that less than half of all severely injured victims are taken to level I trauma centers (1A).(15) This practice has probably led to the rather high (10%) rate of secondary transfers of urgent patients within 2 h. Such secondary transfers further increase the workload on EMS and hospital personnel and may hamper the capability of the health system to react in case of a second attack. The concept of a level I trauma center has been repeatedly shown to improve delivery of care and outcome for severely injured trauma patients (2A).(16) Thus, evacuation should preferentially be to the best-equipped, best-trained facility, i.e., the highest level of trauma care available in the region. However, this may cause saturation of that facility and a dramatic fall in the level of care provided. Therefore, severely injured victims with obvious head injury are taken to a level I trauma center while the remaining severely injured victims are distributed evenly between level I and level II trauma centers. Moderately and lightly injured victims are distributed evenly among the remaining trauma and medical centers (1A).(17)

WHERE, HOW, AND BY WHOM SHOULD TRIAGE BE PERFORMED?

The most experienced trauma surgeon should perform triage at the ambulance unloading bay. Severely injured victims with immediate life-threatening injuries will be directed to a Trauma Room. The remaining victims will be taken to the general emergency department. Identification of severe injuries in these chaotic circumstances can be facilitated by external signs of trauma such as penetrating head and torso injuries, and injuries to 4 or more body regions (1A).(18)

> In the presented case the victim was short of breath, sustained multiple, diffuse shrapnel injury and burns, a combination of injuries which facilitated triage to a Trauma Room. In other cases, victims are taken to the general admitting area where the severity of their injuries is diagnosed. These victims may then be secondarily transferred to the Trauma Room. And vice versa, victims who are initially triaged to the Trauma Room are then re-evaluated and if found to sustain only moderate injuries and secondarily transferred to the admitting area.
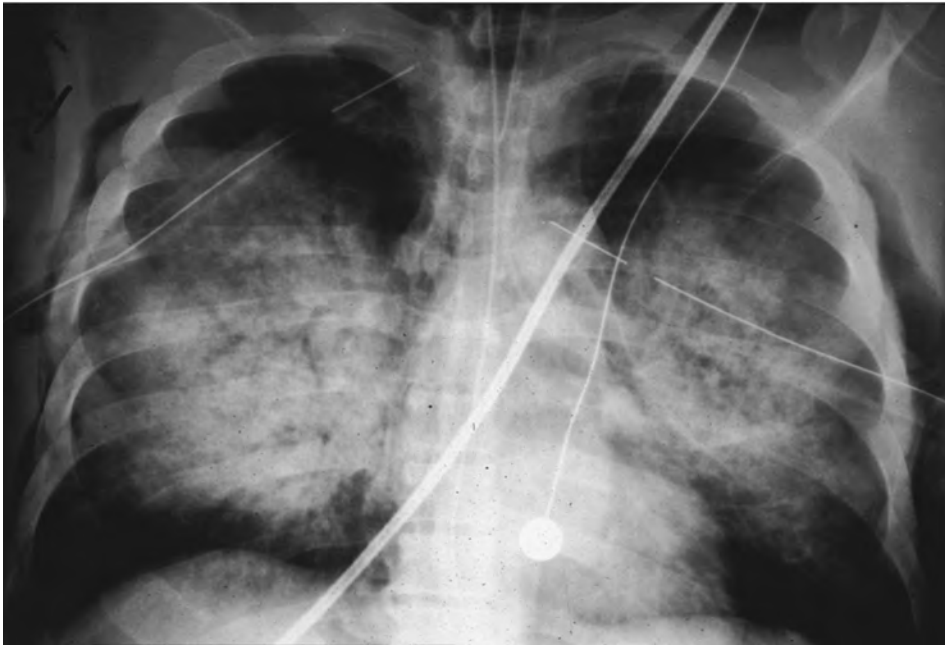
Figure 21.1 Chest X-ray of a victim of a suicide bombing attack aboard a bus, showing typical bilateral patchy infiltrates in a butterfly distribution. Also, note bilateral chest tubes.

WHAT IS THE MECHANISM OF PRIMARY BLAST INJURY AND HOW COMMON IS IT?

The size of the explosive charge determines the velocity of the blast wave and the duration of overpressure. Detonation of a 50 lb charge of TNT creates an overpressure 100–150 psi. Primary blast injury (PBI) mostly occurs in gas-containing organs such as the lungs, middle ear, and bowel. The three mechanisms which cause tissue damage are termed implosion, spalling, and acceleration–deceleration (2b, 2B).(19, 20) The phenomenon which occurs as a shock wave travels through an organ containing pockets of gas is defined as an implosion. The pockets of gas are initially compressed by the surrounding fluid. As the shock wave passes, these pockets of gas expand rapidly, resulting in an internal explosion. Spalling occurs at the interface between media of different densities when the shock wave passes from a high density to a lower density substance. In the lungs these pressure differentials tear the alveolar walls and disrupt the alveolar/capillary interface. The result is the formation of giant emphysematous spaces filled with blood. The phenomenon which occurs as a blast wave accelerates tissues of different densities at different rates causing soft tissue destruction is termed acceleration and deceleration injury. Acceleration caused by the blast wave of an organ with elastic fixation such as bowel mesentery and rapid deceleration caused by the anatomic fixation can result in organ damage (true blast injury mechanism). More commonly, acceleration–deceleration is responsible for tertiary blast injury caused by the bumping of the body against other objects (2C).(21)

BLI is caused by the effects of the blast wave on the lung parenchyma and has the highest morbidity and mortality of primary blast injuries. Pulmonary barotrauma is the most common critical injury to victims close to the blast center, and 45% of fatalities of bomb explosions suffer from BLI (1A).(22) In 17% of deaths lung injury is the sole finding (1A).(23) One half of victims exposed to overpressures of 50–100 psi will manifest pulmonary injury. Exposure to overpressures greater than 200 psi is universally fatal (1B).(24)

WHAT IS THE PATHOPHYSIOLOGY OF BLI?

The abrupt movement of the chest wall caused by blast waves does not allow equilibration of the compressed air by venting it out through the trachea (2A).(25) Propagation of pressure waves through the lung results in alveolar wall injury and disruption of the alveolar/capillary interface (2A).(26) The combination of injury to airway epithelium and the creation of giant emphysema expose the patient to air penetration into the pleura and mediastinum. The development of acute lung injury and adult respiratory distress syndrome (ARDS) ensues. Additionally, lung parenchyma is sheared away from the vascular tree by acceleration–**deceleration forces, resulting in the development of alveolar–venous fistulas. Air is then forced into pulmonary veins which can lead to arterial air embolism (AAE). Signs of AAE include air in the retinal vessels, arrhythmias, blindness, chest pain, and neurological deficits and may appear very early (2B).(27) AAE to the brain or heart may be the most common cause of rapid death solely caused by BLI in immediate survivors and often occurs at initiation of positive pressure ventilation (PPV) (2B, 2A).(28, 29)

HOW IS BLAST LUNG INJURY DIAGNOSED?

BLI manifests most commonly as pulmonary contusions (2B).(30) In confined spaces injury is often bilateral and diffuse and more severe than in open spaces. Considerable blast loads cause ecchymoses, usually in parallel bands which correspond to intercostal spaces (2A).(31) Even higher energy blast waves cause characteristic multifocal hemorrhages under the pleura (2A).(32) Stress-induced tears of air–tissue interfaces cause hemopneumothoraces, traumatic emphysema, and alveolovenous fistulas.

Symptoms and signs of BLI include cough, dyspnea, chest pain, hypoxia, tachycardia, apnea, wheezing, and hemodynamic instability (1B).(33) Diagnosis is based on mechanism of injury, i.e., exposure to a blast wave, hypoxia, hypercarbia, and typical

imaging findings. Clinical examination can be misleading as a tool for identifying patients with BLI. Indeed, several victims of terrorist attacks walked into the ER by themselves, only to quickly deteriorate within minutes. Respiratory rate can aid in diagnosing BLI and victims of bomb explosions with a mean initial respiratory rate of 25 breaths/minutes were significantly more likely to require mechanical ventilation than victims with a mean rate of 13.5 breaths/minutes (p=0.047) (2B).(34)

Chest radiographs are used to determine the presence and severity of BLI and to monitor its progression (Figure 21.1) (1B). (35) Frequent findings include lung contusions, pneumothoraces, pneumo-mediastinum, and subcutaneous emphysema (1B). (36) The severity and grade of BLI can be established based on the combination of chest X-ray findings, the ratio of PaO_2/FIO_2 and the presence of bronchopleural fistula.

> In the presented case the patient was short of breath with decreased breath sounds bilaterally, an obvious sign of BLI. Chest X-ray confirmed the diagnosis.

WHAT IS THE TREATMENT OF BLI?

The respiratory management of BLI is challenging because of the combination of hemodynamic shock, severe lung injury and barotrauma, each of which may require contradictory therapies. Adequate analgesia and aggressive chest physiotherapy are fundamental elements of therapy. All victims with suspected BLI should be given high-flow oxygen. Diuretics may be used in the setting of hydrostatic fluid overload as evidenced by elevated pulmonary capillary wedge pressures in hemodynamically stable patients.

In victims suffering from BLI the presence of pneumothoraces and hemothoraces should be aggressively diagnosed and treated in order not to further compromise lung function. The degree of injury to lung parenchyma is often such that it is necessary to insert several chest tubes in order to adequately drain the pleural cavity and allow proper ventilation and oxygenation. Severe BLI is often associated with poor lung compliance and the use of low tidal volumes (5–7 ml/kg), pressure-controlled ventilation combined with positive end-expiratory pressure (PEEP), and permissive hypercapnia should be started a soon as the patient exhibits the first signs of acute lung injury (1B, 2B).(37, 38) Use of PEEP of 10–20 cm H_2O and a low FIO_2 are acceptable early in management. Inverse inspiratory-to-expiratory ratios, independent lung ventilation, high-frequency jet ventilation, and nitric oxide should be used to manage refractory hypoxemia.

Treatment in a hyperbaric chamber is the definitive therapy for AAE (2C).(39) Increased ambient pressure will decrease emboli size and promote their rapid absorption. The immediate decrease in bubble size may be responsible for the rapid response to therapy that has been observed in some cases. Several animal studies have shown that maintaining hyperbaric therapy for prolonged periods (29 h), decreased blast mortality from 60 to 0%. There is little data on the effectiveness of hyperbaric therapy for human AAE.

> In the presented case the victim showed obvious signs of respiratory compromise and therefore, bilateral chest tubes were rapidly inserted. Since her respiratory situation improved, she was only intubated following the decision to perform laparotomy.

WHAT IS THE ROLE OF NEGATIVE LAPAROTOMIES AND SHOULD DAMAGE CONTROL SURGERY BE UTILIZED IN THESE CIRCUMSTANCES?

Terror-related explosions typically generate mass casualties and a "minimal work-up approach is advocated by some to facilitate the inflow of patients and prevent inundation of the admitting facility (1B).(40) This practice has lead to a 100% rate of negative laparotomies following the London attacks and a 42.9% rate following the Madrid attacks (1A).(41) Non-therapeutic laparotomy may have substantial negative impact on patient management and resource utilization. Increased morbidity, inappropriate use of invaluable human resources and operating room time, and deferral of definitive orthopedic and reconstructive procedures are some of the detrimental side-effects of negative laparotomy. Exploratory laparotomy may be justified in extreme cases for patients in the operating room with persistent and/or unexplained hemodynamic shock.

The approach to intra-abdominal injury following terrorist explosions should be similar to injury caused by other mechanisms of trauma. The rate of injury to hollow viscera is high injury (8.8% of admissions) and patients need to be carefully evaluated for such injury. Imaging modalities such as focused abdominal sonography for trauma (FAST) followed by computerized tomography should be utilized extensively to diagnose intra-abdominal injury following mass casualty incidents (1A). (42) Diagnostic peritoneal lavage can be performed to rule out injury to hollow viscera for victims undergoing other surgical procedures. Due to the possibility of delayed presentation of abdominal injury, catheters can be left in situ for up to 72 h for continued abdominal monitoring.

There is controversy regarding the role of abbreviated, or damage control laparotomy following mass casualty incidents. Following the July 7, 2005, terrorist attack on the London mass transit system, the authors reported that surgery was performed in a damage control mode. The reasoning was to quickly clear the operating rooms and thus facilitate emergency treatment for other victims (1B).(43) On the contrary, experience from Israel has shown that the decision to perform damage control surgery should not depend on logistic considerations but rather upon the specific medical needs of the patient. Damage control surgery should, however, be utilized if and when the expected influx of patients will bring about a steep decline in the level of care, such as may happen following an attack of colossal magnitude (1A).(44)

WHAT IS THE PATTERN OF INTRA-ABDOMINAL INJURY?

Missiles generated by an explosion travel at a lower velocity compared with GSW (300–400 m/sec vs. 800–1,000 m/sec, respectively).
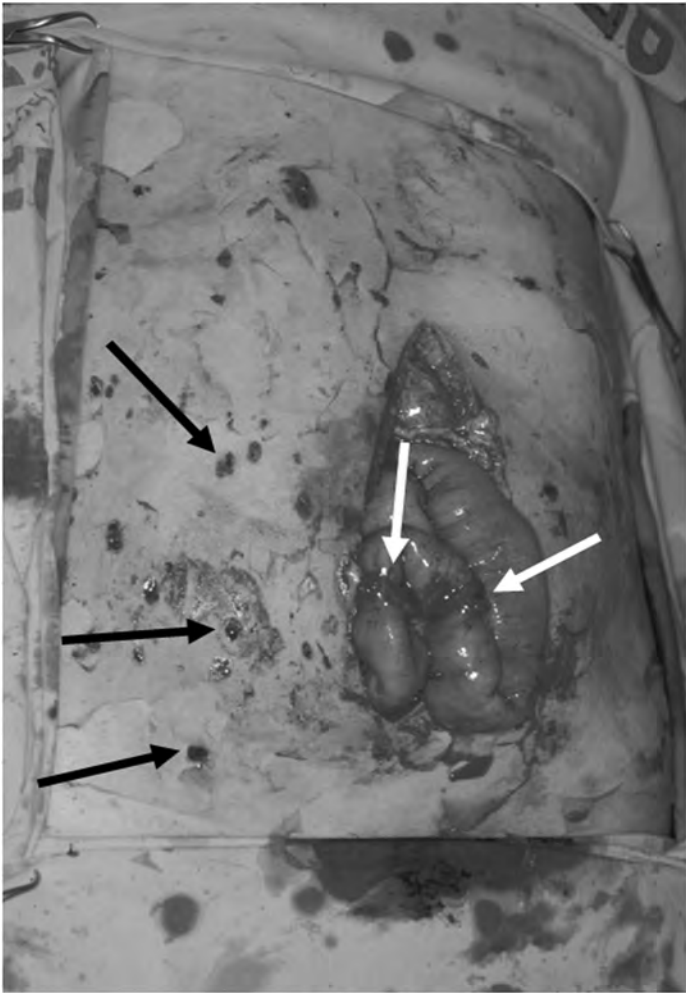
Figure 21.2 Abdominal wall of a victim of a suicide bombing attack. Note multiple shrapnel entry sites (black arrows) and penetrating injury to the small bowel (white arrows).

The damage inflicted will depend on velocity, mass, and distance from the explosion s epicenter (2B).(45) Victims of terrorist explosions sustain multiple entry sites to the torso, which cause the overwhelming majority of intra-abdominal injuries following terror-related explosions. The pattern of intra-abdominal injury following terrorist explosions is similar to the pattern of injury caused by GSW (1A).(46) Injury is most often to the large and small bowel and in nearly a fifth of cases there is injury to more than one segment of bowel. The multiplicity of fragments penetrating the abdominal region over a broad area probably causes this pattern of injury (Figure 21.2). Organs which are partially sheltered by bony structures, such as the liver, spleen, and kidney, are relatively more protected from injury due to the lower energy associated with bomb-related shrapnel.

> In the presented case the victim did not show obvious peritoneal signs and it was therefore justified to perform CT. Although the energy content associated with bomb shrapnel is considerably lower than the energy content of GSW, the pattern of intra-abdominal injury is similar and mandates an identical approach.

HOW COMMON IS TYMPANIC MEMBRANE RUPTURE AND WHAT IS ITS SIGNIFICANCE?

The ear is the most sensitive organ to blast injury, and auditory injury has been reported in up to 41% of survivors following bombing attacks (2A).(47) Peak overpressures as low as 5 psi can rupture the tympanic membrane (TM) and overpressures of 15 psi will cause TM rupture in 50% of victims. Blast overpressure tears sensory cells from the basilar membrane, which eventually heals with scar leading to continued symptoms (2A).(48) Attack setting will determine the frequency of auditory injury and ranges from 8% in open spaces to 50% in confined spaces (1A).(49) Hearing loss may be conductive due to TM rupture, ossicular damage, or serous otitis. It may also be sensorineural due to cochlear damage.

Immediate otoscopic examination for TM rupture should be performed by an otolaryngologist in all cases. Treatment consists of removal of debris from the external canal by suction under microscope and keeping the ears dry. Symptoms and signs immediately following the attack included aural fullness (88.2%), tinnitus (88.2%), otalgia (52.9%) ear discharge (52.9%), and dizziness (41.2%). Normal hearing following TM rupture is uncommon and hearing loss can present as mixed (61.8%), sensorineural (26.5%), or conductive (8.8%). Even at 6-month follow-up some form of hearing loss can persist in up to 80% of victims (2B).(50)

The role of TM rupture as a predictor of primary blast injury is unclear. Several authors advocate the value of routine otoscopy in triaging victims of terror bombing attacks to identify those suffering from severe PBI in general, and BLI in particular (2C).(51) Experience from Israel does not support such a pivotal role for the otoscopic examination (1A).(52) Indeed, more than one-third of victims with BLI do not have tympanic membrane rupture at all. TM rupture is possibly associated with BLI in confined spaces such as buses (2A).(53)

> In the presented case the patient immediately complained of tinnitus. Otoscopic examination was performed as part of the secondary survey in the ER and revealed bilateral TM rupture, typical of bombing attacks in confined spaces.

ARE BURNS COMMON AMONG SURVIVORS?

High-explosives produce higher temperatures for shorter periods of time than gunpowder, usually resulting in a fireball at the time of detonation. The intensely hot flames created (up to 3,000°C) cause burns of varying degrees and depths, usually to victims in close proximity to the detonation (2C).(54) Burns have been regarded as uncommon after a blast and traditional thinking associated burns with severe injuries, most commonly so severe as to be incompatible with life. Indeed, results from Israel show that victims with extensive burns (>30% body surface area) rarely survive (1A).(55) For example, none of the patients with extensive burns who were injured aboard buses survived. However, burns of lesser degrees are quite common among survivors (27.3 %) and necessitate adequate fluid resuscitation as well as local wound treatment. Burns are usually located on exposed body parts, surprisingly not facing the blast s epicenter.

The essentials of managing burns following terrorist bombing attacks are similar to burns caused by other causes. Nevertheless,

the complexity of injuries and related trauma need some special considerations. Among survivors of terror attacks, hypovolemic shock is frequent in the acute stage, resulting from blast and penetrating injuries. Burns may further worsen this condition due to fluid lost through the affected body surface area and into the interstitium. Fluid resuscitation is the primary therapy. However, large volume fluid resuscitation may result in respiratory deterioration in the presence of acute lung injury (1A).(56)

Patients suffering severe blast injury especially blast lung, as well as penetrating injuries from shrapnel in combination with burns benefit from invasive monitoring. Invasive monitoring optimizes fluid management. Central venous pressure catheter is routinely placed. Pulmonary artery catheters are placed only in those patients showing significant hemodynamic instability. Additional methods used to optimize fluid management are trans-thoracic or trans-esophageal echocardiogram (2A).(57)

Burn wound debridement is essential in lowering the bacterial load and reducing the incidence of septic episodes. Definitive wound closure may take time in cases of extensive injury. In these patients, topical antibiotics are the single most important factor in minimizing septic complications. Mechanical wound care is a very important adjunct to the application of topical antibiotics, allowing maximal penetration to the wound surface (1B).(58) Early burn excision and skin grafting is the standard of care for full thickness burn wounds (2A).(59) Early excision and grafting result in increased survival, decreased infection rates, and decreased length of hospital stay.

Terror-related burn victims also sustain a combination of blast and penetrating injuries. Thus, early excision is usually delayed until victims are stable enough. Autologous skin grafting may be delayed even further, depending on the overall status of the patients. Early treatment of partial thickness burn wound consists of mechanical debridement with wet gauzes. Burns involving small BSA are treated with topical antimicrobial agents, while larger areas are treated with homografts. Homografts cover the wounds for 10–14 days and provide protection from desiccation and infection.

> In the presented case the victim suffered from second-degree burns over 10% of her BSA. Burns over 30% BSA and full-thickness burns are associated with proximity to the explosive device and a poor outcome.

CONCLUSIONS

Terror-related blast generated by suicide bombing attacks results in multi-dimensional injury, which is a combination of blast, penetrating wounds, and burns. Victims of indoor attacks sustain more BLI and burns. The work-up and management of these victims includes extensive utilization of imaging modalities and a multi-disciplinary approach.

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22 Pediatric blunt trauma

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Trauma-related injuries are the leading cause of death in children over the age of one.(1) Management of pediatric blunt trauma patients requires a unique subset of skills and knowledge. While many common themes are shared between adult and pediatric trauma patients, the diagnostic approach and ultimate management is often markedly different. Regardless of the age of the patient, the majority of traumatic injuries in the United States are the result of blunt trauma, with motor vehicle collisions being the most common mechanism. Children are more likely to be pedestrians in these types of crashes, as compared to adults.(2) In contrast to penetrating trauma, blunt trauma often presents a greater challenge to the surgeon in determining the scope and severity of the injury and—subsequently—the decision for operative intervention.

This chapter will present a case involving a pediatric trauma patient and subsequently discuss, in a systems-based manner, the evaluations, and treatment decisions unique to children.

> **CLINICAL CASE**
> Your Emergency Department receives a call from the EMS team as they are en route with Baby A, a 6-month-old male infant with deformed bilateral lower extremities. His vital signs are currently stable and he is on supplemental oxygen only.

Preparation for the Pediatric Trauma Patient

As outlined in other areas of this book, activation of a trauma team, based on the acuity of the anticipated injury, ensures that children will receive the appropriate intensity of care upon arrival and that all necessary specialists will be available. This includes alerting the radiology department, pediatric intensive care unit, and, based on the surgeon's judgment, the operating room. Radiology, laboratory, and respiratory technicians should be readily available.

The trauma exam area should be warmed, especially if an infant is expected, to minimize insensible heat losses. As compared to adults, young children and infants are more prone to such losses given their larger body-surface-area-to-weight ratio and their often thinner subcutaneous fat layer. If prolonged exposure to cold temperatures has been reported, warming blankets and heated IV fluids should be ready in the trauma room.

The trauma exam rooms should be equipped with patient size-appropriate endotracheal tubes (ETT) and devices for venous, arterial, and intraosseus (IO) catheterization. As outlined in Table 22.1, ETTs range in size from 2.5 to 8.0 mm (10–34 French units) for pediatric patients, depending on the age. To that end, it is imperative that not only a wide range of equipment sizes are on hand but that charts are available to assist trauma personnel in selecting the most appropriately sized equipment. The Broselow tape uses the patient's length and estimated weight to assist the physician in calculating weight-based medications and in choosing the correct size instruments for pediatric trauma patients. It is designed to be used for use in children less than 12 years old (up to 36 kg).

Once the child arrives in the trauma resuscitation area, each team member should participate in their clearly defined role, as assigned prior to the arrival of Baby A to the trauma room.

Table 22.1 Endotracheal Tube Size and Position in Pediatric Patients.

Age	Internal Diameter (mm)	External Diameter (mm)	French Units	Distance from Lip to End of ETT (cm)
Premature	2.5	3.3	10	10
Term newborn	3.0	4.0–4.2	12	11
1–6 mo	3.5	4.7–4.8	14	11
6–12 mo	4.0	5.3–5.6	16	12
2 yr	4.5	6.0–6.3	18	13
4 yr	5.0	6.7–7.0	20	14
6 yr	5.5	7.3–7.6	22	15–16
8 yr	6.0	8.0–8.2	24	16–17
10 yr	6.5	8.7–9.3	26	17–18
12 yr	7.0	9.3–10	28–30	18–22
≥14 yr (female)	7.0	9.3–10	28–30	20–24
≥14 yr (male)	8.0	10.7–11.3	32–34	20–24

Source: Miller(129).

Each team member should be fully prepared to begin immediate assessment and resuscitation of Baby A upon his arrival.

> When the infant arrives in the trauma room, he is crying loudly as he is moved on the backboard from the stretcher to the exam table. A correctly sized cervical collar is in place. The baby's parents report that their son accidentally fell while being bathed. Vital signs are as follows: HR 182, BP 78/42, RR 38, O_2 saturation 98% on 100% face mask.

INITIAL RESUSCITATION AND EXAMINATION OF THE PEDIATRIC TRAUMA PATIENT

Primary Survey

Upon arrival to the trauma room, immediate assessment of the airway, breathing, circulation, disability, and exposure should occur, in accordance with advanced trauma life support (ATLS) guidelines. While the components of the primary survey are addressed sequentially, in practice, some will be handled concurrently by the experienced team. The trauma leader is responsible for coordinating the team's evaluation and ensuring that each aspect of the primary survey is safely verified in order.

Airway. The first area to be assessed—both in the field and upon arrival in the trauma room—is patency of the airway. While a crying or talking child does demonstrate a patent airway, constant reevaluation is needed. The member of the trauma team at the head of the bed is responsible for monitoring the airway for patency and for cervical spine (c-spine) immobilization throughout the exam. Any change in respiratory effort, or in the quality of respirations, must prompt reassessment for impending respiratory failure and the need for intervention. The intervention can be as simple as suctioning the oropharynx or performing a jaw-thrust maneuver (while maintaining c-spine neutrality), or it may require endotracheal intubation. In infants, signs of respiratory distress can include head bobbing, stridor, cyanosis, nasal flaring, or supraclavicular or subcostal retractions ("belly breathing"). Toddlers and older children may be anxious or stridorous. A distressed-appearing toddler with cyclical use of accessory respiratory muscles to assist with breathing is pending respiratory failure. A Glasgow Coma Score (GCS; Table 22.2) of less than 8, absence of the gag reflex, or arterial oxygen tension <50 mmHg (or arterial carbon dioxide tension >50 mmHg) are also

Table 22.2 Glascow Coma Scale for Children (Modified) and Adults.

	Infant, <1 year old	Infant, 1–2 years old	Toddler, 2–5 years old	Child, > 5 years old	Adolescents / Adults
Eye Opening (possible points: 4)					
4	Spontaneous	Spontaneous	Spontaneous	Spontaneous	Spontaneous
3	To loud voice / shouting	On verbal command	On verbal command	On verbal command	Opens eyes to verbal stimuli
2	To pain	To pain	To pain	To pain	Opens eyes to pain
1	No eye opening	No eye opening	No eye opening	No eye opening	No eye opening
Verbal Response to Voice or Questioning (possible points: 5)					
5	Babbles appropriately	Babbles appropriately	Appropriate words/ responses	Oriented	Oriented
4	Crying, consolable	Crying, consolable	Inappropriate words	Confused	Confused
3	Inconsolable crying/ screaming	Inconsolable crying/ screaming	Inconsolable crying/ screaming	Inappropriate words	Inappropriate words
2	Grunting or moaning to pain	Grunting or moaning to pain	Grunting or moaning to pain	Incoherent words	Nonspecific sounds
1	No verbal response	No verbal response	No verbal response	No verbal response	No verbal response
Motor Functioning (possible points: 6)					
6	Spontaneous movement	Follows commands	Follows commands	Follows commands	Follows commands
5	Localized movement toward painful stimuli	Localized movement toward painful stimuli	Localized movement toward painful stimuli	Localized movement toward painful stimuli	Localized movement toward painful stimuli
4	Withdraws to painful stimuli	Withdraws to painful stimuli	Withdraws to painful stimuli	Withdraws to painful stimuli	Withdraws to painful stimuli
3	Flexes in response to painful stimuli	Flexes in response to painful stimuli	Flexes in response to painful stimuli	Flexes in response to painful stimuli	Flexes in response to painful stimuli
2	Extends in response to painful stimuli	Extends in response to painful stimuli	Extends in response to painful stimuli	Extends in response to painful stimuli	Extends in response to painful stimuli
1	No response to painful stimuli	No response to painful stimuli	No response to painful stimuli	No response to painful stimuli	No response to painful stimuli

Source: Simon JE.(131).
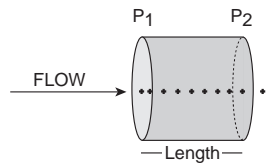
Flow through a tube (or catheter) = [π * (P1-P2) * (radius)4] / [8*(viscosity)(length)]

Figure 22.1 Poiseuille's Law: Flow through a Tube.

Table 22.3 Normal Weight and Vital Signs for Age in Pediatric Patients.

Age	Weight Range (kg)	Heart Rate (bpm)	Systolic Blood Pressure (mmHg)	Respiratory Rate (bpm)	Urine Output (cc/kg/hr)
Infants, age <1 yr	0–10	<160	>60	<60	2
Toddlers, 1–3 yrs	10–14	<150	>70	<40	1.5
Preschoolers, 3–5 yrs	14–18	<140	>75	<35	1
School age, 6–12 yrs	18–36	<120	>80	<30	1
Adolescents, >12 yrs	36–70	<100	>90	<30	0.5

Source: American College of Surgeons Committee on Trauma(130).

indications for immediate intubation. There should be a low threshold for securing a reliable airway in children who have sustained major trauma to the face or neck. This includes children with burns to any part of their body, but in particular those with facial burns or suspected smoke inhalation injury (examine for charring in the nose or mouth, singed nasal hairs or eyebrows, or history of exposure to fire or smoke). Laryngeal and tracheal edema associated with smoke inhalation can often occur quickly and may preclude placement of an endotracheal tube. It should be anticipated that fiberoptic intubation may be necessary in these children, and the appropriate staff and equipment must be readily available.

Breathing. Once the airway is secured, movement of air should be assessed and supplemental oxygen be provided. A non-rebreather mask provides maximal oxygen delivery to a spontaneously breathing child. Important questions in evaluating 'Breathing' are: What is the respiratory rate? Does the patient have bilateral breath sounds? Does the chest move in a symmetric fashion with each breath?

Breathing requires coordination of the lungs, diaphragm, and chest wall. Injury to any of these structures can have deleterious effects on respiratory effort and, ultimately, gas exchange. Any identified obstacles to breathing should be quickly addressed. This may include needle decompression for suspected tension pneumothorax or chest tube thoracostomy for pneumothorax or hemothorax with respiratory compromise. It is of particular importance to evaluate for pleural air, fluid, or blood in the unconscious patient, as intubation and positive-pressure ventilation could lead to further deterioration in this clinical situation.(3)

In the given clinical scenario, the loud cry of the patient is a good sign that he has a patent airway and air is moving well. As this status can change rapidly in children, "Airway" and 'Breathing' need to be regularly re-assessed.

Circulation. Reviewing this patient's vital signs reveals a heart rate that is outside the normal range for a 6-month-old infant. Recognizing the normal vital sign ranges for infants and children (Table 22.3) is of critical importance in managing pediatric trauma patients. In pediatric patients, tachycardia and altered skin perfusion are often the only clinical signs of hypovolemia. While hypotension is often an indicator of decreased volume status in adults, blood pressure is not an accurate measure of hemodynamics in children because it is one of the last clinical measures to change in hemodynamically unstable infants and children. Coupled with their innate reserves, tachycardia, and

vigorous peripheral vasoconstriction allow infants and children to maintain cardiac output and blood pressure in the face of significant volume losses.(4) Clinical evidence of shock may not be apparent until a child has lost more than 25% of his or her blood volume and may manifest precipitously with cardiovascular collapse.(5)

In addition to hemodynamics, the "Circulation" assessment also addresses intravascular (IV) access, as it allows correction and maintenance of circulation deficits. Concurrently with the physical examination, a separate team member should gain IV access. In children, vascular access can be achieved in several ways, with the most common method being the insertion of two short-length, wide-bore peripheral IV catheters. If this proves impossible, IO access in the proximal tibia is an option for children under the age of 6 years. Both resuscitation fluids and blood products can be infused through an IO line. Surgical cutdown—typically over the greater saphenous vein—is another option for obtaining emergent access in a child. As a last resort, central venous access via the external jugular, internal jugular, subclavian, or femoral veins can be obtained. Central lines, however, are a substandard method for high flow resuscitation due to their long length and small diameter. As explained by Poiseuille's law, which is outlined in Figure 22.1, as the length of the catheter increases and/or radius decreases, flow through the catheter decreases. The additional disadvantages of the central venous catheter include the risk of pneumothorax or hemothorax during insertion, bleeding from the insertion site, or inadvertent arterial puncture or cannulation. While there is a risk of infection associated with central venous catheters, careful attention to removing "trauma room lines" in a timely fashion can minimize this risk.

Pediatric trauma patients should initially be resuscitated with warmed Lactated Ringer's solution in accordance with ATLS guidelines, which are well established for both adults and children. Resuscitation begins with fluid boluses of 20 mL per

kilogram. This can be repeated three times to achieve hemodynamic stabilization (total of 60 mL per kilogram). If an adequate response from the fluid boluses has not been achieved after three boluses, consideration is given to transfusion of packed red blood cells (pRBCs), in bolused volumes of 10 mL per kilogram.(6) While concern for elevation of intracranial pressure, and thereby decreasing cerebral perfusion pressure (CPP), is valid in children with known or suspected head injury, hypovolemia must still be corrected using the weight-based parameters described above.(7) If there is a particular worry about affecting CPP, the assistance of a neurosurgical team can help with monitoring and fluid management.

Disability. If not already secured, the cervical spine must be immobilized in a hard cervical collar. Assessment for disability during the primary survey serves to identify and quantify gross neurological deficits. A more thorough evaluation for neurological injury is performed as part of the secondary survey and is discussed later. Enough information should be obtained to calculate the GCS. Pupil response, general mental status, and gross motor function are the key points of interest during the primary exam, as deficits may signal significant intracranial pathology.

Exposure. Removal of all of the patient's clothing occurs in a concurrent manner with the earlier elements of the primary survey, with a goal to identify life-threatening injuries that might be hidden by clothing (e.g., pooling blood from a stab wound to the back or an open mid-shaft femur fracture). Following the assessment, warm blankets or warming devices should cover the patient. Maintaining a normal body temperature (or rewarming a hypothermic patient) is of particular importance in pediatric patients, as they quickly lose body heat due to their high surface-area-to-body-mass ratio. Hypothermia results in an unnecessary expenditure of energy in a critically ill patient.

> Assessment of Baby A reveals a vigorously crying infant, without evidence of stridor, cough, or increased work of breathing. He is tachycardic. His blood pressure is appropriate for his age and he has palpable radial, femoral, and dorsal pedis pulses in his extremities. Two intravenous lines are placed and Lactated Ringer's solution is infused. His pupils are examined and are equal and reactive to light. Baby A continues to cry vigorously. He is inconsolable (verbal score 3). His eyes are open (eye score 4) and he spontaneously moves each extremity (motor score 6). His modified GCS is 13. His cervical spine is appropriately immobilized in a properly fitted collar. The infant's clothing is removed to facilitate performance of the secondary survey. To maintain body temperature, warmed blankets are placed on the infant and an overhead portable heat lamp is positioned above the exam table.

Secondary Survey

The secondary survey is your opportunity to examine the child from head to toe, allowing for a more complete assessment of tenderness, vascular injury, neurologic deficit, and orthopedic

instability. The secondary survey, however, should not proceed until the primary survey is complete—including establishing adequate IV access—and any problems with airway, breathing, circulation, disability, and exposure have been addressed.

Head. The entirety of the head and face is closely inspected for injury. This may manifest as frank bleeding, hematoma, or bony deformity. The scalp, peri-orbital structures, maxilla, and mandible are palpated for bony instability. The patient is asked to bite down gently, if feasible, to demonstrate any malocclusion. The eyes are examined for pupil size and conjunctival hemorrhage; visual acuity is assessed, if possible. A lighted speculum is used to examine the ear canals and the nose. The presence of blood or fluid in the ear canals, behind the tympanic membranes, or in the nasal passages suggests a basilar skull fracture. Any suspicion for intracerebral injury warrants immediate neurosurgical evaluation.

Neck. The absence of neurological deficit—particularly in the pediatric patient—does not exclude spinal cord injury in children. As noted above, the cervical spine must be immobilized immediately in all trauma patients until the proper examination and imaging can be performed to exclude spinal injury. All aspects of the neck are inspected and palpated during the secondary survey. Anteriorly, the trachea is be palpated to assess for deviation and the soft tissue is evaluated for crepitus, which might suggest large airway injury (i.e., trachea or bronchus). The lateral aspects of the neck are then inspected for traumatic injury. As outlined below, the cervical spine is inspected and examined completely.

Chest. The entire chest should be inspected for ecchymoses, penetrating injury, bony abnormality, and asymmetry in chest wall expansion. Palpation of the chest looks for instability or tenderness. While rare in children, flail chest (fracture of two or more consecutive ribs in two or more places) can cause significant breathing difficulty and can be addressed acutely with splinting and adequate analgesia. The lungs should be auscultated in the anterior, posterior, supraclavicular, and lateral fields to evaluate for abnormal or decreased breath sounds. This examination is particularly important if the patient required intubation, as right or left mainstem intubation may manifest as unilateral decreased breath sounds, and must be differentiated from a unilateral hemo- or pneumothorax. It is critical to be alert for the manifestations of tension pneumothorax, as this condition can be rapidly fatal but is also readily treated by emergent needle decompression and chest tube thoracostomy.

Abdomen. Visual examination and palpation of the entire abdomen looks for signs of intraperitoneal injury, including tenderness, distention, tympany, and organomegaly. Patterns of bruising and abrasions (such as the "seat-belt sign," discussed later) should be noted. The surgeon must be particularly alert to the presence of peritoneal signs, including rebound tenderness, tenderness to percussion, and/or involuntary guarding as they indicate the need for a more detailed evaluation of the abdomen, or for emergent laparotomy.

Pelvis. Assessment for pelvic injury includes inspection for ecchymoses or blood at the urethral meatus (in males) as well as palpation for instability and tenderness. This examination consists of gentle pressure to compress and then to distract the

pelvic ring. Aggressive distraction must be avoided so as not to worsen any bleeding associated with an existing pelvic fracture. A child with an unstable pelvic girdle, especially in the setting of hypovolemia, should undergo immediate pelvic stabilization, as described later.

Extremities. The extremities are examined for evidence of penetrating injury, abrasions, lacerations, hematoma, and gross bony deformity. The presence of vascular injury is assessed by checking pulses in all four extremities. An absent or decreased pulse prompts a closer evaluation of the limb for penetrating injury, fracture, or dislocation that may have compromised blood flow. Hand-held Doppler examination of pulses can provide an immediate assessment, but more definitive evaluation requires a vascular ultrasound or angiogram, with the assistance of a vascular surgeon as appropriate. Color and temperature of the extremities may also help identify those patients with vascular insufficiency, hypovolemia and/or hypothermia.

Spine/Back. After the anterior aspects of the examination have been completed, evaluation of the back and spine ensues. Ensuring adequate stabilization of the head and cervical spine by one member of the trauma team, the child is rolled onto his or her side in a slow and controlled fashion. After inspection of the back for signs of injury, the entirety of the spine—from the base of the skull to the coccyx—must be palpated. Any indication of spinal instability, gross deformity, or tenderness prompts immediate immobilization of the affected area and consultation with a neurosurgeon. The back should also be palpated for tenderness in the areas of the scapula, posterior ribs, flank, and posterior pelvis and hips.

When the child is rolled for examination of the back, a rectal exam assessing rectal tone, rectal wall integrity, tenderness, and presence of gross blood is also performed. If there is no contraindication, this is a good time to remove the backboard, as well as any clothing still present. While necessary for initial patient management in the field, prolonged use of the backboard risks the development of pressure sores.

Neurologic exam. It is often most efficient and comprehensive to evaluate for neurological defects in a concurrent manner as the child is examined from head to toe. Neurological examination of the head should include evaluation of the pupils and cranial nerves. Assessment of motor and sensory function is assessed in the face, extremities, and trunk, including testing of reflexes.

Baby A remains tachycardic but is not in respiratory distress. His heart rate is 188 and his oxygen saturation by pulse oximetry is 99% on non-rebreather face mask. The child is resuscitated with a 20 cc/kg bolus of Lactated Ringer's solution, after which his heart rate is 170. Labs were drawn and are pending. The secondary survey reveals a distended abdomen with tenderness to deep palpation, bilateral deformed thighs, and multiple old bruises of the arms and legs. The radiology technicians are available in your exam room and are awaiting your instruction.

DIAGNOSTIC STUDIES FOR THE PEDIATRIC TRAUMA PATIENT

Once initial stabilization of the patient has occurred, the decision regarding additional diagnostic work-up ensues. Early detection of trauma-induced injuries in children requires adept clinical surveillance skills in addition to properly utilized radiographic studies.

Laboratory Studies

Laboratory investigation for adult and pediatric patients is a standard element of the initial work-up at most trauma centers. The panel of laboratory tests typically includes measurement of the hematocrit and hemoglobin, platelets, white blood cell count, electrolytes, glucose, INR and partial prothrombin time, liver enzymes, amylase, and lipase. Some centers also evaluate serum creatinine kinase and troponin levels as an indicator of cardiac and/or muscle injury. In a study of 714 hemodynamically stable adults with suspected blunt abdominal trauma, alanine aminotransferase (93% sensitivity and 70% specificity) and white blood cell count (81% sensitivity and 53% specificity) were most sensitive and specific for intra-abdominal injury.(8) The utility of amylase levels in diagnosing and monitoring pancreatic injuries is discussed below. Despite some correlations, there is no evidence in the pediatric literature to support a single laboratory value as an indicator of intra-abdominal pathology. Measurement of basic laboratory values, such as those listed above, provides a baseline for further evaluation and allows sequential monitoring (e.g., serial hematocrits), if needed.

Plain Films

Plain films of the chest and pelvis, obtained via a portable x–ray machine, are the first line of diagnostic imaging in trauma patients. Antero-posterior (AP) films of the chest and pelvis are generally the initial, and minimal, studies required. Chest radiography enables the surgeon to quickly evaluate for conditions that are life threatening and require immediate intervention, such as hemothorax, pneumothorax, or pneumomediastinum. Additionally, a chest x–ray provides a gross assessment of diaphragm integrity, mediastinal size, parenchymal lung injury, and the presence of rib or vertebral fractures. Free air is not reliably appreciated on a portable chest x–ray but may be assessed with a cross-table film of the lower chest or abdomen. The pelvic x–ray provides information about potential fractures of the pelvis, sacrum, or lumbar vertebrae.

In children with cervical spine tenderness—or those with a history or mechanism of injury that suggests spinal cord trauma—plain films of the cervical spine should be obtained as an initial radiographic investigation into spinal injury. In general, this includes the majority of pediatric trauma patients. Options for imaging the neck with plain films include AP, lateral, odontoid, and swimmer's views, with AP and lateral views constituting the minimum views needed for evaluation. The need for additional plain films of the neck or for a CT of the c-spine is determined in consultation with a pediatric radiologist.

The use of full-body digital x–ray is a relatively new modality for imaging pediatric trauma patients.(9) This technique provides a rapid full-body radiograph, enabling the surgeon to quickly assess for orthopedic injury and other pathology on a single image (Figure 22.2). An additional benefit of this type of

Figure 22.2 Full-Body Digital Imaging.

Full-body digital radiograph of a pediatric trauma patient demonstrating (a) herniation of abdominal contents into the chest suggestive of diaphragm injury, (b) fracture of the right iliac crest, and (c) a femur fracture.
Source: van As(9) with permssion.

imaging, as compared to a CT scan, is the markedly decreased amount of ionizing radiation exposure for the child. Its disadvantages include limited availability of the scanner and an inability to assess for visceral injury outside of what would be grossly appreciated on a plain film.

For instances where additional imaging is needed for diagnostic purposes, such as suspected extremity fractures, it is best to wait on obtaining non-essential studies until the child is stabilized and appropriately worked-up for life-threatening injuries. With rare exceptions, there is generally little harm in delaying x–rays for a possible foot fracture, for example, until after the child is safely in the intensive care unit.

Ultrasound

The presence of peritoneal fluid collections is often predictive of solid organ injury and has been found to correlate with ultimate mortality.(10) In the pediatric population, ultrasound is a particularly attractive option to assess for the presence of free fluid in that it offers repeatable, noninvasive, real-time imaging without the use of ionizing radiation.

Focused abdominal sonography for trauma—or focused abdominal sonography for trauma (FAST)—has become the

standard of care in assessing adult trauma patients, nationwide. These exams allow rapid detection of intra-abdominal fluid, and multiple predictive models have been created that utilize FAST exam results as predictors of the need for operative intervention. The FAST exam evaluates for free fluid or blood in four abdominal regions: left upper quadrant/spleen, right upper quadrant/hepato-renal space (Morrison's pouch), pericardium, and pelvis/bladder. In experienced hands, a thorough evaluation will only take minutes.

The use of FAST examinations as a screening tool for pediatric trauma patients is starting to gain attention, and its use in pediatric trauma centers is becoming more frequent. Pediatric FAST examination as part of the initial evaluation of a trauma patient has been supported in multiple studies, including those by Soudack et al. who demonstrated 92.5% accuracy, 97.2% sensitivity, and 95.5% specificity of FAST in predicting intraperitoneal injuries in children.(11, 12) Interestingly, other studies have found that FAST examinations in children appear to have markedly better specificity but lower sensitivity for intra-abdominal injury, than FAST examination in adults.(13) While FAST may provide important information about the presence of intra-abdominal fluid, it is limited by the fact that it cannot diagnose organ-specific injuries. Additionally, with non-operative management playing such a major role in many cases of pediatric solid organ injury, the identification of free abdominal fluid by FAST does not mandate operative exploration.

While emergent laparotomy is warranted in hemodynamically unstable trauma patients who have a positive FAST exam for free fluid, additional imaging is usually warranted in hemodynamically stable children with a positive FAST exam. The current standard for abdominal and pelvic evaluation, in the setting of suspected injury, is CT scanning. In addition to providing good detail of the solid organs, the IV contrast used in CT scanning can also provide information about organ perfusion or bleeding, and CT scans are particularly sensitive in picking up free air in the abdomen. At this time, the literature does not support the use of FAST examination as a replacement for CT scanning in pediatric blunt trauma patients.(14) For those children with stable vital signs, free fluid on ultrasound or CT scan does not by itself mandate operative exploration, as solid organ injury is often managed, at least initially, non-operatively.

A new modality for trauma assessment—contrast-enhanced ultrasonography—has been found in small studies to be almost as accurate in predicting abdominal solid organ injury as contrast-enhanced CT scanning in pediatric blunt trauma patients, with a sensitivity and specificity of 92.2 and 100%, respectively. (15) Use of this technology is limited by availability of ultrasound equipment, technicians, and pediatric radiology staff trained to evaluate the images.

Computed Tomography Scanning

The use of CT scanning for evaluating intra-abdominal anatomy in pediatric trauma patients has increased markedly over the past 10 years and currently represents the standard of care in evaluating solid organ or visceral injuries. In addition to identifying injured organs, modern grading scales rely on CT findings to quantify the degree of injury to organs such as the liver or spleen.

While CT scans scan can provide important radiographic information about solid organ, vascular, or visceral injury, specific criteria for when to order a CT scan have yet to be well defined in the pediatric trauma literature. Ideally, CT scans should be performed with oral and IV contrast (unless a head injury is suspected, for which a noncontrast head CT should first be obtained), although this is not always feasible given the age or clinical status of the patient. The use of CT scanning is appropriate in hemodynamically stable children who have clinical signs or symptoms—such as abdominal pain or intra-abdominal fluid on FAST examination—suggestive of intra-abdominal or pelvic injury and has likely decreased the rate of negative trauma laparotomies.(16)

Hemodynamically unstable pediatric trauma patients should never be transported to the CT scanner without proper resuscitation. The safest place for these children, initially, is in the trauma room, where resources are readily available for resuscitation and injury management. For children whose clinical condition does not improve with crystalloid and/or blood product resuscitation, the optimal management is generally to take them to the operating room for exploration.

Despite the increased application of CT scanning in the work-up of pediatric illness and injuries, it is not without drawbacks. Radiation exposure is of significant concern in pediatric patients, and the amount of radiation required for CT scans is much higher than that needed for plain film x–rays. Children's organs—particularly the thyroid, breast, and gonadal tissues—are very sensitive to ionizing radiation and the effects of radiation exposure are cumulative over a lifetime. There is much debate in the literature as to the exact risks of future malignancy for children who undergo CT scan at a young age. The risks of developing a fatal cancer over the course of a lifetime due to a single CT scan as a young child may be as high as 1 in 1000. (17) The literature on these risk assessments is difficult to compare, however, because protocols for scanning pediatric patients vary from institution to institution and, therefore, so does the amount of radiation exposure. Additionally, tissue absorption of ionizing radiation is different amongst infants, young children and older children, again making outcomes studies very difficult to compare. What is known is that ionizing radiation has a cumulative effect over a lifetime, and cancers induced by radiation may take years to decades to develop. Therefore, the effects of radiation exposure are likely more dangerous in children as compared to adults.(18)

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) is not an appropriate imaging modality in the initial work-up of pediatric trauma patients. Despite its increasing popularity, MRI is still significantly limited in availability, efficiency, and speed. The increased length of time needed to complete an exam, as compared to CT, is prohibitive in the initial evaluation of a critically injured child. Additionally, MRI is often difficult in the pediatric population as many children are not able to remain motionless for the duration of the examination. This often necessitates sedation, which could be unfavorable in a trauma patient.

MRI does have advantages in the less acute setting, with the most substantial of these, in children, being the lack of exposure to ionizing radiation. In the trauma population, MRI is often utilized to identify ligamentous injuries to the spine, an insidious and potentially life-threatening injury.

Diagnostic Peritoneal Lavage

The use of diagnostic peritoneal lavage (DPL) in the initial work-up of adult and pediatric patients with concern for intra-abdominal injury has declined. CT scanning and bedside ultrasonography (FAST) have essentially replaced DPL in the work-up of abdominal injury in children, despite some studies demonstrating DPL to have greater sensitivity than CT for intra-abdominal injury in children. Meyer et al.(19) studied 60 children who sustained blunt abdominal trauma and found DPL to have a 94% sensitivity for intra-abdominal injury, compared to 67% for CT (sensitivities were 100% for both modalities). However, DPL has no localizing capability as far as intra-abdominal injuries are concerned and can only provide information regarding the presence or absence of hemoperitoneum or enterosuccus. Further, with non-operative management being the standard of care for even significant solid organ injury, the presence of peritoneal blood has less impact on management than previously.

In situations where FAST or CT is not available, DPL can be performed in children in a manner similar to that of adults. Care should be taken when performing this procedure in children, as their abdominal wall is often markedly thinner than that of an adult and iatrogenic injury can occur to the abdominal organs. (6) Additionally, if there is any concern for a pelvic hematoma, particular care must be taken to avoid violating the contained hematoma and causing uncontrolled bleeding. This is accomplished by making the incision above the umbilicus, rather than below it.

In adults, greater than 100,000 RBCs per mm (3) on DPL warrants emergent laparotomy. Similar findings in children do not necessarily mandate operative intervention *if* the child responds to fluid resuscitation. The presence of white blood cells, fecal material, or bile on DPL are indications for emergent laparotomy in both adults and children.(6)

Grading of Evidence for the Diagnostic Evaluation of Traumatic Injuries in Children

Recommendation	Grade
Focused abdominal sonography is useful in identifying intra-abdominal injuries in pediatric blunt trauma patients	1B/strong recommendation, moderate quality evidence(11, 12, 13)
Computed tomography of the abdomen and pelvis is useful in identifying intra-abdominal injuries in pediatric blunt trauma patients	1B(14, 16)

Source: Gordon G(128).

Plain films of the cervical spine, chest, pelvis, and bilateral lower extremities are obtained in the Trauma Room. These reveal several right rib fractures and bilateral mid-shaft femur fractures. Baby A is then taken for a CT scan of the chest, abdomen, and pelvis using intravenous contrast. This scan demonstrates jejunal bowel wall thickening with a small amount of free peritoneal fluid. There is no intraperitoneal free air. The remainder of the CT scan is remarkable only for the multiple right-sided rib fractures. How should these injuries be managed? Is operative intervention warranted? What is the likely clinical course and outcome of these findings?

Specific Thoracic, Visceral, and Musculoskeletal Injuries

Concurrent orthopedic and solid organ injuries are not uncommon in the pediatric trauma patient. However, with the higher compliance of a child's chest wall, significant intra-thoracic and intra-abdominal injuries can occur without an overt fracture. A high clinical suspicion is needed for occult injuries during the evaluation of children subjected to blunt trauma.

Injuries to Cardiovascular System

Children are susceptible to great vessels injuries following blunt trauma due to the elasticity of their thoracic cavity, which allows transfer of kinetic energy to the internal organs, thereby causing damage.(20) This flexibility of a child's rib cage can allow injuries to the heart, lungs and great vessels following a blunt impact, without evidence of rib fractures. While cardiac injury is a rare consequence of blunt trauma in children, myocardial contusion, valve damage, pericardial effusion and myocardial wall rupture can occur.(21,22) These injuries can manifest as arrhythmias, hemodynamic instability, aneurysm, shock, or death.(22) Great vessel disruption following blunt trauma is exceedingly rare in children.(22)

Blunt cardiac injury is more likely to be present in children who have sustained multi-system trauma and those involved in motor vehicle collisions.(21, 23) A high degree of suspicion is often necessary to diagnose these injuries as, with the rare exception of devastating injuries such as ventricular rupture, they are often insidious in nature. Hemodynamic compromise may be a late sequela of cardiac injury, occurring up to 48 h after the initial injury.(23) On clinical examination, awake and neurologically intact children may complain of chest pain. Examination may demonstrate external signs of chest trauma, although studies of blunt chest trauma in children reveal that physical examination, including cardiac auscultation, in the setting of blunt cardiac injury, is often non-diagnostic.(21) Further evaluation for blunt cardiac injury can utilize echocardiogram, electrocardiogram and measurement of cardiac enzymes (i.e., CPK-MB). Even in combination, however, these modalities are marginal at best for identifying blunt cardiac injury in children.(21)

The degree of injury to the chest often predicts overall outcomes. Children who require cardiopulmonary resuscitation after blunt trauma have a very low likelihood of survival, as it is a marker for significant force absorbed by the child.(24) As is the current management guideline for adults, prolonged resuscitation or heroic efforts—such as emergency department thoracotomy—for children who have sustained blunt trauma and are pulseless in the field, should not be pursued as they do not improve overall survival.(25, 26) Cause of death in these children is usually neurologic in nature and therefore cardiac-based interventions and resuscitation are often futile.(24)

There are situations where aggressive intervention for cardiac arrest is warranted. For the pediatric trauma surgeon, one of the most important is cardiac arrest or pulseless electrical activity secondary to external compression of the ventricles, especially if vital signs are lost after the child arrives in the trauma room. Cardiac tamponade is caused by the accumulation of blood or fluid within the pericardial sac, which interferes with normal filling and contraction of the heart. It is more commonly associated with penetrating trauma but can be a rare complication of blunt chest trauma. Tamponade is a life-threatening emergency that must be recognized and treated immediately. Needle decompression of the pericardial sac uses a large-bore (16- or 18-gauge) 6-in. needle, with a 30–60cc syringe attached via 3-way stopcock. The needle is inserted at a 45° angle, starting at the xiphochondral junction, and carefully advanced cephalad while aiming at the tip of the left scapula. With continuous aspiration on the syringe during needle advancement, it should be apparent when the pericardial sac is entered. The procedure is ideally assisted with an ultrasound to ensure proper placement. If the hemopericardium has already clotted, evacuation may be futile through a needle and is an indication for operative intervention by thoracotomy. If the patient's condition allows, it is best to perform this additional procedure in the operating room; however, an emergency department thoracotomy may be necessary and life saving. An emergent thoracotomy is performed by making an incision along the fourth intercostal space. The scalpel is then used to dissect through the intercostal musculature and parietal pleura, with care taken to remain on the superior edge of the fifth rib, thereby avoiding the neurovascular bundle of the fourth rib. A rib-spreader provides exposure, and gentle retraction of the lung will demonstrate the bulging pericardium. The pericardium is opened in a cranio-caudal fashion, to minimize risk of phrenic nerve injury, and the tamponade is released. This approach also enables performance of cardiac massage, if necessary. Ideally, cardiac massage is performed using two hands to compress the heart, as a one-handed approach may cause the fingers to tear through the atria or ventricle.

Imaging or laboratory evaluation specific to myocardial or great vessel injury is not initially warranted for Baby A. However, if he develops hemodynamic instability in the initial 24–48 hours following the traumatic injury, myocardial involvement must be ruled out.

Injuries to the Airways, Chest, and Diaphragm

Blunt chest trauma occurs in 50,000 pediatric trauma patients annually.(27) Mortality rates for children who present with thoracic trauma are 14–28%, and increase to 38–56% if concurrent injuries to the head and abdomen occur.(28) The most common injury is pulmonary contusion (27, 29) followed by hemothorax and pneumothorax.(28)

Thoracic injury is most often seen in traumas involving children as pedestrians who are struck by motor vehicles or after falls from varying heights (28); however, any blunt force to the chest can cause significant pulmonary and diaphragmatic injury in a child. Clinical findings associated with thoracic trauma include chest wall skin abrasions, decreased breath sounds, and respiratory distress.(28)

After completing the primary and secondary surveys, an AP film of the chest should be obtained as part of the initial work-up in a pediatric trauma patient. Blunt trauma to the lungs induces parenchymal hemorrhage, interstitial edema, and alveolar consolidation, which are apparent on imaging as focal or diffuse opacities in the lung fields.(27) While plain films can detect pulmonary contusions, there may be a delay in development of opacities on CXR. CT scanning of the chest can provide additional information to aid in the diagnosis of pleural, parenchymal, and mediastinal pathologies.(28) CT can often identify these injuries earlier and provide a more accurate quantification of the extent of such injuries, as compared to plain films.(27) Findings of widened mediastinum, thoracic spine fractures, upper rib fractures, or pulmonary pathology evident on plain film following blunt trauma in a pediatric patient should prompt further evaluation via CT scanning, with focused investigations as warranted (e.g., CT aortogram for suspected dissection).(30)

As an isolated finding on chest CT, pulmonary contusion has not been found to increase overall mortality (27), although it is not without clinical sequelae, including increased supplemental oxygen requirement, pain, and low tidal volumes with associated atelectasis. Pulmonary contusion is treated with supportive care. It can take as few as 2 days and as many as 7 or more days for clinical and radiographic evidence of pulmonary contusions to resolve.(27)

Tracheal Injuries

In addition to injuries of the lung parenchyma and pleura, blunt force to the chest can damage the airways. Tracheobronchial rupture due to blunt trauma is a rare complication of high-velocity blunt trauma. As reviewed by Ozdulgar et al, right main bronchus injury is the most common finding in this cohort and may be either a complete transection or a partial tear. Physical findings of tracheal rupture include dyspnea, subcutaneous emphysema, cyanosis, and decreased breath sounds. Following chest tube insertion, these patients will typically exhibit a persistent air leak with cervicomediastinal emphysema and residual pneumothorax notable on chest x–ray.(20)

Rigid or flexible bronchoscopy is the gold standard for identifying bronchial tree disturbances and should be performed in those patients whose history, physical exam, or radiographic findings are suggestive of such an injury. It is best to perform this examination in the operating room to ensure that all required instruments are available and to allow immediate repair if an injury is discovered.

Patients with delayed or missed diagnosis of bronchial ruptures may present later with recurrent pulmonary infections due to stenosis of the healed bronchus.(20)

Diaphragmatic Injuries

Like injuries to the great vessels and airways, diaphragm injury or rupture is a rare consequence of blunt trauma in children and usually occurs in the setting of multi-system injuries. Rupture due to blunt force to the chest or abdomen typically occurs on the left postero-lateral aspect of the diaphragm, along the embryonic lines of pleuroperitoneal membrane fusion.(31, 32) A high degree of suspicion is often necessary to detect these injuries. If missed, they can have devastating sequelae including intestinal obstruction, with eventual progression to bowel ischemia, sepsis, and death if they remain undiagnosed.(33)

In one of the larger cohort studies investigating diaphragmatic rupture in pediatric trauma patients, only 46% of patients were diagnosed pre-operatively, with an additional 30% of patients found to have a diaphragmatic injury at the time of surgery.(33) Children may have chest or abdominal pain, respiratory distress, or present in shock, depending on the degree of injury, severity of accompanying injuries, and time elapsed since the initial trauma.(32) There are no physical examination findings that are consistently present in patients with diaphragmatic hernia, although decreased breath sounds may be noted over the area of herniation. Chest radiographs, which are routinely performed as part of the initial work-up of a trauma patient, are suggestive of diaphragmatic injury in less than 50% of children.(31, 32) Chest x–ray findings may include intra-thoracic visceral herniation (evidenced by air-fluid levels or loops of bowel in the chest), hemothorax, or elevated diaphragm.(34) Computed tomography, ultrasonography, or fluoroscopy may provide additional information regarding diaphragm integrity but must be interpreted in the setting of clinical examination and suspicion, as none of these modalities has a high diagnostic sensitivity for rupture in children.

If the diagnosis of diaphragmatic rupture is suspected, operative intervention is mandated, as a delay in treatment may be associated with increased morbidity and mortality.(35) Open surgical repair via laparotomy or laparothoracotomy (depending on the presence of other injuries requiring operative intervention) is the mainstay of treatment. The diaphragm injury can typically be closed primarily, without the need for mesh. The use of intercostal muscle flaps to bridge larger gaps in the diaphragm has been successfully described.(34) The role of laparoscopic exploration and repair for traumatic diaphragmatic hernia is not well defined for pediatric patients; however adult, and some pediatric, literature does support the use of laparoscopy as a diagnostic tool in asymptomatic patients.

Grading of Evidence for the Treating of Traumatic Injuries to the Heart and Lungs in Children.

Recommendation	Grade
Prolonged resuscitation or "emergency room thoracotomy" should not be performed on pediatric blunt trauma patients who were pulseless in the field	1A/strong recommendation, high-quality evidence(24–26)
Computed tomography of the chest is indicated in patients with injuries to the chest wall, physical exam findings suggestive of pulmonary pathology, or those with chest x–ray findings suspicious for pulmonary or mediastinal injury	1B/strong recommendation, moderate quality evidence(28, 30)
Operative exploration should be performed in children with suspected traumatic diaphragmatic injuries	1C/strong recommendation, low-quality or very low quality evidence(31–35)

Baby A does not have evidence on chest x–ray or computed tomography to warrant addition work-up or suspicion for cardiac, great vessel, or pulmonary injury.

ABDOMINAL INJURIES

Gastrointestinal injuries following blunt trauma are more common in children than in adults.(36) This is a function of both anatomy and mechanism of injury. Abdominal injury occurs in blunt trauma due to the transmission of forces from the skeleton to the internal organs. This transmission of kinetic energy is more pronounced in children due to the increased flexibility of the pediatric skeleton, as compared to adults. This is compounded by the fact that a child's intra-abdominal organs are proportionally larger within their abdominal cavity, their rib cage is higher so that it does not fully protect the liver and spleen, and most children have less visceral fat for protection from traumatic forces. Additionally, in cases of children being struck by motor vehicles, the child's smaller stature puts his/her chest or abdomen at the level of the vehicle's bumper, which is in contrast to adults for whom the legs are more likely injured by a car bumper.

Mechanism of injury is an important consideration when evaluating children for intra-abdominal injury. Seat belts, while protective in nature, can cause their own series of injuries. This is particularly true in young children who have outgrown their child safety seat and have been transitioned to a three-point-restraint seat belt, or those traveling in older vehicles offering only single lap belts. Four to 9-year-old children in this "transitional period" are at markedly elevated risk for seat belt-induced injury due to their low center of gravity, the likelihood of the seat belt fitting over the abdomen instead of the pelvis, and a fairly underdeveloped bony pelvis that fails to fully protect the internal organs.(3) For example, in a head-on-motor vehicle crash with significant deceleration forces, a seat belt placed improperly over the abdomen can lead to compression of the fixed duodenum against the lumbar spine, thereby causing injury.(37) A cohort study investigating approximately 13,000 children involved in motor vehicle crashes found that those who were suboptimally restrained (single lap belt only or failure to use child safety seats or belt-positioning booster seats in accordance with National Highway Traffic Safety Administration (NHTSA) age- and weight-based guidelines) were four times more likely to sustain a hollow visceral injury when compared to those who were optimally restrained according to current recommendations.(38)

Another important modality to consider in pediatric abdominal trauma is bicycle-related injuries, in particular those involving a child flipping over or being forced into the handles, which may lead to significant morbidity. The most common mechanism of abdominal injury from handlebars is direct impact into the child from the end of the handlebar.(39) These children, who are essentially "speared" by the handlebars, have a much higher risk of requiring operative intervention for their injuries, as compared to those who sustain injuries due to flipping over the handlebars.(40)

History and physical examination, as outlined above, are critical elements in identifying abdominal injuries in children. Examination of the abdomen may provide clues as to the presence of intra-abdominal injury. A "seat belt sign"—described as bruising or ecchymosis across the lower abdomen—has been associated with an up to 80% likelihood of significant abdominal injury.(38) These children are at risk for both solid organ and hollow viscus injuries from the compressive forces exerted between the child's spine and the seat belt. In a study of 147,985 children involved in motor vehicle crashes, Lutz et al. found that abdominal wall bruising had a 73.5% sensitivity and 98.8% specificity for the presence of significant intra-abdominal injury.(41) Conversely, the absence of abdominal bruising in this large pediatric study had a 99.9% negative predictive value for intra-abdominal injury.(42) In conjunction with the ecchymotic "seat belt sign" across the lower abdomen, some pediatric patients may have lumbar vertebral injury from hyperflexion (Chance fracture), and resultant injury to the jejunum or ileum, a clinical scenario referred to in the literature as the "lap belt complex."(43) This has particular consequence for evaluating intra-abdominal trauma, as the rate of hollow organ injury may be as high as 50% in this cohort of pediatric trauma patients.(43)

Absence of abdominal wall bruising, abrasions, or other visible injury are not sufficient to rule-out intra-abdominal injury. In particular, injuries to the visceral organs and pancreas may have no physical signs appreciable on exam. Additionally, the routine use of a "trauma panel" of laboratory tests, which typically includes measurement of hematocrit, hemoglobin, coagulation studies, electrolytes, lipase, amylase, and urinalysis, has not been shown to have diagnostic predictive value in children with intra-abdominal injuries.(44) In these cases, clinical suspicion and mechanism of injury must guide further imaging and evaluation.

Radiographic evaluation for intra-abdominal injuries has historically involved diagnostic peritoneal lavage. This modality has

been replaced by bedside ultrasonography (FAST) and CT scanning, as discussed previously. The presence of free fluid in any of the quadrants examined via FAST examination necessitates further attention. Intra-abdominal fluid on abdominal CT scan, in the absence of solid organ injury, has been found to correlate with an approximately 25% chance of bowel injury.(45) The risk is 12% if only a small amount of abdominal fluid is seen, but increases to 50% if a moderate amount of free fluid is demonstrated in multiple areas on abdominal CT scan (45). The presence of free fluid should not be used as sole criteria for operative intervention; emergent laparotomy should be based predominantly on clinical findings and *supported* by radiographic evidence.

Regardless of improvement in imaging technology, quality and efficiency, serial abdominal examinations, and assessment of hemodynamic stability remain the best predictors for the need for operative exploration following blunt trauma. While nonoperative management is the mainstay of treatment for most solid organ injuries in hemodynamically stable children, close observation will identify those children who need an exploration.

Specific strategies for managing injuries to the stomach, spleen, liver, pancreas, small intestine, and colon are detailed below.

Traumatic Injuries of the Stomach

Gastric injury can occur when the stomach is forcefully compressed against the spine. The degree of injury can range from hematoma or partial thickness laceration (Grade I) to devascularization of the majority of the stomach (Grade V), as outlined in Table 22.4. Gastric perforation is a rare consequence of blunt trauma. In a retrospective study reviewing 805 cases of gastrointestinal perforation in pediatric blunt trauma patients, the stomach was the site of perforation in only four (<1%).(46) Gastric transection, as a result of blunt trauma in children, is very rare but can present quite dramatically and carries a nearly 50% mortality.(47)

Repair strategies for gastric injuries are based on the extent of gastric perforation and devascularization. Simple perforations can be closed with suture or staples. Resection of part or all of the stomach may be required if the integrity of gastric or gastroepiploic arteries, or their tributaries, have been compromised.

Table 22.4 Classification of Traumatic Injury of the Stomach, Spleen, and Liver.

Grade	Gastric Injury	Splenic Injury	Hepatic Injury
I	Contusion hematoma or partial thickness laceration	*Hematoma* Subcapsular, nonexpanding, <10% of surface area *Laceration* Nonbleeding capsular tear, < 1cm of parenchymal depth	*Hematoma* Subcapsular, nonexpanding, <10% of surface area *Laceration* Nonbleeding capsular tear, < 1cm of parenchymal depth
II	*Laceration* <2 cm in GE junction <2 cm in pylorus <5 cm in proximal 1/3rd of stomach <10 cm in distal 2/3rds of stomach	*Hematoma* Subcapsular, nonexpanding, 10–15% of surface area *or* Intraparenchymal, nonexpanding and <2 cm in diameter *Laceration* Capsular tear with active bleeding, 1–3 cm parenchymal depth	*Hematoma* Aubcapsular, nonexpanding, 10–15% of surface area *or* Intraparenchymal, nonexpanding and <2 cm in diameter *Laceration* <3 cm parenchymal depth and <10 cm in length
III	*Laceration* >2 cm in GE junction >2 cm in pylorus >5 cm in proximal 1/3rd of stomach >10 cm in distal 2/3rds of stomach	*Hematoma* Ssubcapsular, involving >50% of the surface area or expanding *or* ruptured subcapsular with active bleeding *or* intraparenchymal, >2 cm or expanding *Laceration* >3 cm parenchymal depth *or* involves trabecular vessels	Hematoma Subcapsular, involving >50% of the surface area or expanding *or* ruptured subcapsular with active bleeding *or* intraparenchymal, >2 cm *Laceration* >3 cm parenchymal depth
IV	*Tissue loss / devascularization* <2/3rds of stomach	*Hematoma* ruptured intraparenchymal with active bleeding *Laceration* Involving hilar or segmental vessels with major devascularization (>25% of spleen)	*Hematoma* central, ruptured *Laceration* 25–75% of parenchyma destroyed
V	*Tissue loss / devascularization* >2/3rds of stomach	*Laceration* Completely shattered *Vascular* Hilar injury with complete devascularization of the spleen	*Laceration* >75% of parenchyma destroyed *Vascular* Juxtahepatic venous injury involving the retrohepatic vena cava or major hepatic veins
VI			*Vascular* Complete avulsion of the liver

ACS Surgery Principles and Practices(132).

Splenic Injuries

The spleen is the most commonly injured solid organ following blunt trauma and is often the result of direct force to the left upper quadrant. The AAST organ injury scale (Table 22.4) also applies to pediatric patients and is the basis for the current, accepted non-operative management of splenic injury.

In situations of splenic injury, clinical history may be positive for direct trauma to the left upper quadrant. Splenic injury can also occur in rapid deceleration, as the spleen is quite vascular and has many ligamentous attachments that cause capsular tears or rupture. Unlike adults, children rarely have concurrent rib fractures with traumatic splenic injuries, due the elastic nature of the thoracic cavity.(14)

Children with splenic injury may complain of left upper quadrant pain. They may also have shoulder pain—known as "Kehr's sign"—which is referred pain to the left shoulder from diaphragmatic irritation due to the presence of blood. On physical examination, splenic injury should be considered in children with bruising or abrasions in the left upper quadrant, focal, or diffuse tenderness, and abdominal distention. Children with these injuries may present *in extremis* with tachycardia and poor peripheral perfusion, marked by coolness, pallor, decreased capillary refill, and weak pulses. In children, these are ominous signs of hypovolemia and bleeding with impending circulatory collapse. It is again important to remember that hypotension in children is a very late manifestation of even massive blood loss.

FAST examination in the trauma room can be used as an initial modality to assess for splenic injury. It is limited in its ability to only show presence of free fluid and is not appropriate for diagnosing or grading splenic injuries. Children with known or presumed splenic injury who remain hemodynamically unstable despite aggressive fluid resuscitation, those who deteriorate clinically or those with concern for concurrent hollow viscus injury should be taken immediately to the operating suite for exploratory laparotomy. Intraoperatively, every attempt should be made to salvage all or part of the spleen, as post-splenectomy sepsis can be a life-threatening consequence, particularly in children. Options for splenic salvage include splenorrhaphy and partial splenectomy, which enable the surgeon to control bleeding but also preserve some splenic parenchyma, which will hopefully allow the child to have normal immunological functioning. In those children who are hemodynamically stable, CT scanning is the gold standard for evaluating splenic injury. Further, based on accepted radiographic findings, the degree of splenic injury can be graded (Table 22.4). In addition to lacerations and hematomas, CT can also identify active splenic bleeding. As splenic hemorrhage is typically arterial in nature, active splenic hemorrhage is often seen as a "blush" on CT scan, which represents pooling of contrast material within or around the spleen.(42)

The management of splenic injury in children changed markedly in the early 1980s, as the shift away from operative intervention to observation became widely practiced. This was in large part assisted by the development and increased use of diagnostic imaging, such as CT scanning, which allowed these injuries to be easily monitored in a noninvasive way.

Multiple studies have demonstrated that children with Grades I–III traumatic splenic injuries rarely require blood transfusion or operative intervention, 2–10 and 3%, respectively.(48) Based on these findings, guidelines were set forth in 2000 by the American Pediatric Surgical Association (APSA) Trauma Committee as to the management of traumatic injuries of the spleen in children. APSA recommends that children with an isolated Grade I splenic injury should undergo a 2-day hospital observation course, without need for intensive care unit observation. No post-discharge imaging is recommended for these patients. The APSA guidelines are similar for those patients with isolated Grade II and III injuries, however, these patients should be observed for 3 and 4 days in the hospital, respectively.(48) The general guideline for the in-hospital observation is Grade of injury +1, for days of hospitalization.

For those children with Grade IV splenic injuries, intensive care unit admission, typically for a 24-h observatory period, is recommended, followed by a 4-day in-patient observation period.(48) As is the case for those with lower grade injuries, however, routine pre- or post-discharge imaging in a stable, asymptomatic patient has not been shown to affect morbidity or mortality and is thus not recommended.(48, 49) Children with new or persistent abdominal pain, or other symptoms concerning for on-going bleeding from a solid organ injury, should undergo abdominal ultrasound or CT scan.

All children who sustain solid organ injuries to the spleen should refrain from physical activity for a 3- to 6-week period, depending on the grade of the injury (the number of weeks is calculated by adding 2 to the injury grade; e.g., Grade II injury should refrain from physical activity for 4 weeks).(48) These children should also avoid contact sports—such as football, wrestling, and hockey—for a minimum of 2–3 months. Ultrasound and CT scanning are not useful for determining periods of activity restraint, as the integrity of the spleen is not readily quantifiable on imaging studies.(48)

The failure rate of non-operative management for splenic injuries in children is less than 10%.(50–52) This is markedly different from adults with splenic injury, who fail non-operative management up to 24% of the time.(50) Why this difference exists is not well understood. Proposed theories include that by Gross back in 1965, which suggested that an increased anatomical thickness of a child's splenic capsule as compared to an adult's, in addition to larger amounts of elastin and smooth muscle within the splenic vasculature, had a buffering effect with traumatic forces.(50)

The decision to perform a splenectomy is one that must address both the immediate and the long-term sequelae of such an intervention. Post-splenectomy sepsis is a life-threatening condition involving bacteremia from encapsulated bacteria. Its estimated incidence is 0.23–0.42% per year and 3.2–5% over a lifetime.(14, 53, 54) This equates to a 38–69% mortality from post-splenectomy sepsis.(14, 54, 55) All children over the age of 2 who undergo splenectomy should receive post-splenectomy vaccinations against encapsulated bacteria, including meningococcus, *Streptococcus pneumoniae*, and *Haemophilus influenza* (for children under the age of 2 at the time of splenectomy, antibiotic prophylaxis should be started and vaccination should be delayed until after the child's second birthday).(14, 56, 57) Additionally, current recommendations are that children under the age of 5 should be placed on prophylactic antibiotics with penicillin VK or amoxicillin (trimethoprim–sulfamethoxazole for children under age 6 months). Antibiotic prophylaxis can be discontinued at the age of 5 in children who have not had an invasive pneumococcal infection, assuming they have received the recommended vaccinations.(58)

Grading of Evidence for the Treating of Traumatic Injuries of the Spleen in Children.

Recommendation	Grade
Hemodynamically stable children with traumatic injuries to the spleen can be safely managed non-operatively in a closely observed setting	1A / strong recommendation, high-quality evidence(48)

Hepatic Injuries

Traumatic injuries to the liver are the second most common intra-abdominal organ injury following blunt trauma in children. The right lobe is more often injured than the left lobe and injuries can span the scope of small superficial lacerations to deep intra-parenchymal injuries involving biliary and vascular structures. (14, 52) Bleeding is usually secondary to venous involvement (as opposed to splenic injuries, which are typically arterial in nature). Again, the AAST organ injury scale also applies to pediatric liver injuries and is summarized in Table 22.4. Mortality and the need for blood transfusion following liver injury, however, is more strongly associated with injury severity score (ISS) and presence of co-injuries than with grade of liver injury.(14, 59)

As with splenic injury, children with traumatic injuries to the liver may also have "Kehr's sign"—pain that is referred to the right shoulder due to blood irritating the diaphragm. Physical examination in children with hepatic injuries may be normal or may exhibit signs of trauma to the right upper quadrant, such as bruising and abrasions. The abdomen may be tender or distended. Again, vital signs and physical examination are important indicators of intra-abdominal bleeding. Tachycardia or decreased capillary refill in a child should prompt both further resuscitation and evaluation for a bleeding source. In comparison to children with splenic injuries, traumatic liver injuries are more likely to require blood transfusion.(14)

FAST examination is a useful tool for determining if intra-abdominal free fluid is present, and CT scan is the imaging modality of choice for identifying and quantifying hepatic injuries. Since grade of injury does not correlate with mortality, discovery of a hepatic injury on CT scan does not always mandate operative intervention.

Like splenic trauma, the standard of care for managing liver injuries has changed over the past 100 years. Improvements in hemodynamic monitoring and imaging have enabled successful non-operative management of hepatic injuries in a hemodynamically stable child, with success rates ranging from 85 to 97%.(52, 60–63) In a study by Landau et al. investigating 311 children with blunt hepatic injury, only 4% required liver-related laparotomy. All of the children who required laparotomy either presented in shock or became markedly unstable within 12 h of their injury.(60)

In accordance with APSA recommendations, children with Grades I, II, and III hepatic injuries should be observed for signs and symptoms of delayed bleeding for 2, 3, and 4 days, respectively (i.e., injury Grade + 1, in days). Due to the low likelihood of bleeding in these cases, these children do not require intensive care unit admission for the liver injury alone. However, for Grade IV or greater liver injuries—i.e., those with a central ruptured hematoma or laceration involving 25–75% of the liver parenchyma—a 24-h-observation period in a pediatric intensive care unit is warranted. Following discharge from the ICU, the child should be monitored for an additional 4 days in the hospital.(48) Assuming that the child's hospital course is uneventful, no additional imaging is required prior to discharge.

In the 288 children successfully managed non-operatively in the Landau study, there were 12 complications (4%), which included ruptured subcapsular hematoma, abscess, pancreatic pseudocyst, and fat embolism syndrome.(60) Other potential complications associated with non-operative management of traumatic liver injuries include persistent bile leaks and biloma, hepatic artery pseudoaneursym, necrotic gallbladder, arteriovenous fistula, abscess, and delayed hemorrhage (61, 64–66). The likelihood of delayed hemorrhage, which may occur anywhere from 3 days to 6 weeks post-injury, is approximately 1.7% in children.(64)

Controversy exists over how to best manage hemodynamically stable pediatric patients with continued bleeding from a traumatic liver injury. Operative repair via laparotomy has long been the standard of care, however, other options do exist. There are some cases in the literature where transcatheter arterial embolization has been successfully utilized in these situations.(67) The role of diagnostic or therapeutic laparoscopy in children suspected of having blunt hepatic injury (or, more broadly, any intra-abdominal injury following blunt trauma) is controversial. In the adult literature, laparoscopy is supported as an initial diagnostic step prior to planned laparotomy in hemodynamically stable blunt trauma patients with suspected intra-abdominal injury. In this setting, it may decrease the rate of negative laparotomies. Laparoscopy for traumatic injury, however, fails in its ability to fully evaluate for solid organ injury, particularly that of the liver and spleen. Evidence supporting the use of laparoscopy in pediatric trauma patients is limited to case reports and small, underpowered studies.(68, 69)

Children with unstable vital signs despite appropriate resuscitation and a known or suspected liver injury should undergo exploratory laparotomy. Additionally, Grade V and VI liver injuries, which include lacerations involving more than 75% of their livers and complete vascular avulsion of the liver, require operative repair.

In the operating suite, hepatic hemorrhage can be controlled and/or repaired through several different methods. If the child remains unstable, or if the intervention is taking place in a facility unequipped to care for complex pediatric trauma patients, the abdomen should be explored and peri-hepatic packs should be placed to provide a tamponade effect. This is performed by placing packs over and around the liver until the bleeding is controlled. Peri-hepatic packing will usually tamponade hepatic bleeding of any nature, although it is typically more effective for bleeding sources from the right lobe. The abdominal fascia is then left open so that the child can be returned to the intensive care unit (or transferred to a pediatric trauma center) for resuscitation and stabilization. To provide coverage, either the skin is closed or large sterile adhesive drapes are placed. Definitive repair is delayed until the child is stable enough for surgery and abdominal closure and should usually take place within 24–48 h.

As an option to standard abdominal packing techniques, Iuchtman et al.(70) reported the use of a mesh wrap technique for controlling massive liver bleeding in four pediatric blunt trauma patients. The mesh is wrapped around all or part of the

liver, creating a "neocapsule" that provides a tamponade effect, while maintaining its elasticity and compressibility for up to 10 weeks.(70) All the four children in their study had eventual recovery and return to normal activities.

For those children who can tolerate repair at the time of laparotomy, proximal control of bleeding must be obtained to fully appreciate the location and extent of the injury. In patients with Grade IV and V injuries, the Pringle maneuver can assist in differentiating between bleeding from branches of the hepatic artery or portal vein (which stops during the maneuver) and bleeding originating from hepatic veins or the retrohepatic vena cava (which does not stop during the Pringle maneuver).

The incidence of bile duct injuries in children following blunt trauma is rare. They are often initially missed, even during trauma laparotomy. When suspected, HIDA scan is the preferred tool for the initial identification of biliary leak.(71) In a small study using HIDA scan to evaluate biliary injuries in pediatric trauma patients, this imaging modality was able to differentiate intrahepatic versus extrahepatic bile duct injuries but could not specifically localize such injuries.(71) More detailed imaging of the biliary tree in those children with suspected biliary pathology should be pursued with endoscopic retrograde cholangiopancreatography (ERCP).

Regardless of biliary or vascular involvement, all children with traumatic injuries to the liver should refrain from full-contact activities and sports for a minimum of 3–6 months. General physical activity should be limited for a period equal to the injury grade plus 2 weeks (e.g., patient with a Grade IV injury should refrain from physical activity for 6 weeks).

Grading of Evidence for the Treating of Traumatic Injuries of the Liver in Children.

Recommendation	Grade
Hemodynamically stable children with Grade I through IV traumatic injuries to the liver can be safely managed non-operatively in a closely observed setting	1A/strong recommendation, high-quality evidence(48, 52, 60–63, 71)
Children with Grade V and VI hepatic injuries require operative exploration and repair	1A(48, 52, 60–63, 71)
Where available, a mesh wrap can be used effectively to tamponade massive liver injuries	1C/strong recommendation, low-quality or very low-quality evidence(70)
Hepatobiliary iminodiacetic acid (HIDA) scanning should be performed in children with suspected injury to the biliary tree following blunt trauma	1C(71)

Traumatic Injuries of the Pancreas

The pancreas and duodenum are at risk of being injured during blunt abdominal trauma due to their fixed position against the spine in the retroperitoneum. This anatomy allows direct compression of these organs between the spine and an outside force, such as a seat belt. Pancreatic injuries can range from crush-type disruptions to complete transection, the degree of which is largely dependent on the nature of the compressive abdominal force and the subsequent deceleration forces associated with the trauma. The majority of traumatic injuries are pancreatic contusions. Nonetheless, pancreatic injury in children following blunt trauma is rare, occurring in only 1–2% of all cases.(72)

Most traumatic injuries to the pancreas occur from bicycle-related incidents, during which the child is struck in the abdomen by the bicycle handle.(73) Outside of mechanism of injury, clinical history often provides little evidence for pancreatic injury. In a study of 14 children with duodenal and or pancreatic injuries following blunt trauma, Plancq et al. found that most children with pancreatic injury had abdominal pain, although few had accompanying tenderness, nausea, or emesis.(74) There are no physical exam findings specific to pancreatic injury in a pediatric blunt trauma patient. Obvious signs of abdominal trauma in the epigastric or left upper quadrant, as evidenced by ecchymosis or abrasions in those areas, should raise suspicion for pancreatic trauma.

Amylase is often ordered as part of the "trauma panel" of laboratory tests performed on patients with trauma-related injuries. Hyperamylasemia may be present in children with pancreatic injuries, however, the presence or degree of hyperamylasemia has not been shown to correlate with the severity of pancreatic injury. (74, 75) Amylase levels may initially be normal in a child with pancreatic injury following abdominal trauma. Serial amylase levels, however, can play an important role in following children with suspected pancreatic injuries in the setting of normal or equivocal radiographic findings as most pancreatic injuries will eventually result in an elevated serum amylase level.(75)

Radiographic diagnosis of pancreatic trauma offers unique challenges in children. Bedside FAST examination will rarely provide clues to pancreatic injury. CT diagnosis of pancreatic injuries can also be difficult in part due to the small size of the pancreas in children. Additionally, the relative lack of retroperitoneal fat surrounding the pancreas in children makes diagnosis based on peri-pancreatic changes—such as fat-stranding and edema—more difficult in comparison to adults.(72) Even in the setting of pancreatic injury, CT scanning will often be devoid of findings in the acute setting. Some findings, however, such as fluid in the lesser sac, are highly suggestive of pancreatic trauma.(72)

Management of traumatic pancreatic injuries in the pediatric patient is a controversial topic and one that is made more difficult by the lack of literature specific to the pediatric population. Extrapolation from adult studies tends to guide the management of traumatic pancreatic injuries in children. Non-operative management with serial abdominal examinations and routine ultrasonography to assess for contusions, ductal obstruction, and pseudocyst formation can be pursued safely in the majority of patients. Most pancreatic contusions will resolve within 4–10 days with non-operative management, which includes bowel rest with nasogastric tube decompression and total parenteral nutrition.

(14, 75, 76) The most common complication of non-operative management is pseudocyst formation, but other complications include fistula formation, hemorrhage, sepsis, prolonged hospitalization, and death.

Pancreatic injury with associated hemorrhage is an indication for exploratory laparotomy. Trauma laparotomy in situations where pancreatic injury may be a possibility should involve retroperitoneal exploration and direct visualization of the pancreas. Visualization of a retroperitoneal hematoma in the upper portion of the abdomen should raise suspicion for a pancreatic injury and mandates complete inspection of the pancreas.(77) This is performed by an extended Kocher maneuver to visualize the anterior and posterior aspects of the head of the pancreas, followed by opening of the gastrocolic ligament to enter the lesser sac and visualize the neck and body of the pancreas. In situations where there is a concern for ductal integrity, intraoperative needle cholangiogram can be performed.

Outside of bleeding, the decision to operate on pancreatic injuries often depends on the presence and degree of ductal disruption. Children with traumatic pancreatic duct injuries may have fewer complications if operative intervention for their injury is undertaken within 24 h of presentation.(78) If a ductal injury is suspected, ERCP can be performed. ERCP has the advantage of being both diagnostic and, potentially, therapeutic if stents can be placed endoscopically across the disruption. However, the use of this modality in the acute setting for critically ill children is limited due to the technical difficulty of performing ERCP on a small child and the requirement of general anesthesia. Additionally, there exist concerns that ERCP could introduce bacteria into a sterile lesser sac fluid collection or cause post-ERCP pancreatitis.

The pediatric trauma literature is consistent in its recommendations of early distal pancreatectomy for those children with distal duct transection or parenchymal injury with suspected duct involvement.(75, 79, 80) Aggressive surgical management, including operative intervention within the initial 24 h following the traumatic injury, has been shown to reduce the likelihood of morbidity (e.g., development of pancreatic pseudocysts, pancreatitis, need for drainage procedures) in patients with distal ductal injury.(75, 78) Distal pancreatectomy should be performed in a spleen-preserving manner, if possible, to avoid the complications associated with post-splenectomy sepsis in children. Non-operative management of distal duct disruptions will usually result in pancreatic tail atrophy and possible development of pancreatic pseudocysts. However, these outcomes may ultimately have little impact on long-term health and pancreatic exocrine and endocrine function.(81)

In regards to more proximal ductal injuries, including those in the head of the pancreas, there are no clear recommendations in the current pediatric literature. Whether to intervene early and perform more aggressive resections and/or roux-en-Y duct drainage with bypass procedures versus non-operative management with expectant intervention, either percutaneously or operatively, if pseudocysts or fistulas develop, is widely debated.(75, 78, 82, 83) The availability of a skilled pediatric endoscopist and/or interventional radiologist will influence the decision to operate or to observe such injuries.

For those children who do develop pseudocysts as a result of pancreatic trauma, repeat imaging is necessary to evaluate their resolution or growth. Small pseudocysts will often resolve following a period of bowel rest, whereas larger cysts may require percutaneous drainage following a period of maturation, which usually takes 4–6 weeks.(14) Percutaneous drainage of peri-pancreatic collections in the setting of on-going abdominal pain and hyperamylasemia is also recommended to alleviate symptoms.

Grading of Evidence for the Treating of Traumatic Injuries of the Pancreas in Children.

Recommendation	Grade
Non-operative management of traumatic pancreatic injuries—including serial abdominal examinations and routine ultrasonography—can be pursued in the majority of children	1C/strong recommendation, low-quality or very low-quality evidence(14, 75, 76, 78)
Pancreatic injury with associated hemorrhage is an indication for exploratory laparotomy	1B/strong recommendation, moderate quality evidence(14, 75, 76, 78)
The use of ERCP in evaluating traumatic injuries in child is limited to centers with physicians with extensive experience in pediatric ERCP	1C(76)
Early surgical intervention and distal pancreatectomy should be performed for children with distal pancreatic duct transection or parenchymal injury. This should be done in a splenic-salvage manner, if possible	1C(75, 78–80)
Small traumatic pancreatic pseudocysts can be observed. Larger cysts that persistent for more than a month or those that are symptomatic (e.g., abdominal pain, hyperamylasemia) should be percutaneously drained	1C/strong recommendation, low-quality or very low-quality evidence (children) (14, 75, 78, 82, 83); *however, in adults, 1A/strong recommendation, high-quality evidence*

Small Bowel Injuries

The incidence of small bowel injury in children following blunt abdominal trauma has been reported to be between 1 and 15%, with the lower estimations found in the more recent literature. (84–88) The jejunum and ileum are the most likely sites of gastrointestinal perforation following blunt trauma in children. (46) These injuries are plagued by delay in diagnosis because, with the exception of free air in the abdomen, there is a lack of

physical exam and radiographic findings specific to this diagnosis. Whether delay in diagnosis actually affects long-term outcomes in these children has been contested in the literature, without clear conclusions.(88, 89)

A higher likelihood of small bowel involvement has been found in children with injuries due to assault and in those with simultaneous pancreatic or other solid organ injuries.(43) It is the number of concurrent solid organ injuries that appear to be the risk factor for bowel injury, not the severity of such injuries.(43) Blunt intestinal injuries without a clear mechanism of injury should raise suspicion for non-accidental trauma.

Children with blunt small bowel injuries may present with abdominal pain, nausea, and vomiting. In children with abdominal pain, some correlation appears to exist between the amount of abdominal tenderness and the severity of the bowel injury.(84) Small bowel injury may present with local or diffuse abdominal tenderness. Occasionally, children with traumatic intestinal injury will have no tenderness or be unable to localize abdominal pain due to distracting injury or neurological impairment. As described above, the presence of a "seat belt sign," the "lap belt complex," or other areas of abdominal hematoma or ecchymosis should raise suspicion for intra-abdominal injury, including that involving the small bowel. The "lap belt complex" relates the presence of flexion-distraction injuries of the spine (most commonly in the lumbar region)—collectively referred to as "Chance fractures"—and small bowel injury. In these situations, the small bowel (and other intra-abdominal) organs are forcefully compressed against the seatbelt as the spine flexes forward, thereby resulting in blunt injury.

Findings on plain film suggestive of duodenal injury include scoliosis, loss of the right psoas shadow, air along the right psoas margin, or air around the upper pole of the kidney (due to retroperitoneal duodenal rupture). These findings should prompt evaluation with more advanced imaging, such as CT scan with oral and intravenous contrast.(74) Pneumoperitoneum on plain film is also suggestive of small bowel injury in a child who sustained blunt abdominal trauma and is an absolute indication for operative exploration, without the need for CT scanning.(88)

While ultrasound has advantages as an imaging modality in children (repeatable, no radiation exposure, fast), its sensitivity for small bowel injuries in children is user dependent and low. Abdominal CT scan can assist in the diagnosis of blunt intestinal injuries in children with suspected injury. The sensitivity of CT for identifying intestinal injury has been reported between 25 and 93%, although the positive predictive value was found to be low (65%) in one study examining 214 pediatric trauma patients.(90, 91) Aside from free air, CT findings suggestive of small bowel injury include free intraperitoneal fluid in the absence of solid organ injury and thickened or fluid-filled loops of bowel, although each of these findings is often subtle and might only be appreciated by a physician experienced at reading pediatric CT scans.(91) While there may be some wall thickening or luminal impairment visible on CT scan, the diagnosis of duodenal hematoma is best made by an upper gastrointestinal contrast study, which in the setting of intramural hematoma will demonstrate luminal deformity with partial or complete obstruction.(74)

Laparotomy is indicated in hemodynamically stable children with peritonitis, free intraperitoneal air, or extravasation of enteral contrast on abdominopelvic CT scan.(84, 91) Hemodynamically stable children without significant radiographic findings can be closely monitored with serial abdominal examinations. Development of abdominal tenderness or peritoneal signs during a 24-hour observation period may signal undiagnosed mesenteric or small bowel injury and warrants operative exploration.

Duodenal injuries are managed based on the location and extent of the injury. The majority of duodenal injuries, including intramural hematomas, may be non-operatively managed with nasogastric drainage, bowel rest, and serial abdominal examinations.(74) Failure of non-operative management due to increasing pain or tenderness, hemodynamic decompensation, or continued luminal obstruction may require surgical evacuation of the hematoma.

Duodenal perforation, as evidenced by extravasation of contrast or the presence of intraperitoneal or retroperitoneal free air, requires surgical intervention. Intraoperative exploration of all four of the duodenal segments should be performed, beginning with the pylorus and first segment of the duodenum. A Kocher maneuver is performed to examine the posterior aspects of the second, third, and fourth segments of the duodenum and to visualize the mesenteric vessels posterior to the pancreas. This procedure involves division of the ligament of Treitz. Upon exploration, palpable thickening, mass, or crepitus within the duodenal lumen or wall, or the presence of retroperitoneal fluid or air are highly suggestive of duodenal injury.(92) Children with extensive retroperitoneal inflammation, or those who may not tolerate a lengthy procedure, should undergo a drainage procedure with duodenostomy and/or retroperitoneal drainage tube. If anatomy and clinical status of the patient allow for definitive repair of a duodenal injury, the choice of repair is based on the location and extent of bowel involvement. Focal injuries can often be treated with debridement and subsequent primary closure, with or without duodenostomy tube placement for continued small bowel decompression.(74) Repair is performed in the transverse direction to decrease the likelihood of subsequent luminal stricturing. Jejunal serosal patches may be utilized for larger defects not amenable to primary closure. Segmental resection of the duodenum is an option for more extensive injuries. If primary anastomosis is not possible due to the extent of segmental resection, pyloric exclusion with gastrojejunostomy or pancreaticoduodenectomy (Whipple procedure) should be performed. The rare indication for a Whipple procedure in a pediatric trauma patient is when duodenal and/or pancreatic head injury has resulted in extensive tissue destruction. An accepted maxim is that a Whipple for trauma should only be performed when the trauma has already performed the Whipple.

Injuries to the jejunum and ileum are managed operatively based on the extent of the injury. Small perforations can often be primarily repaired. Larger defects and mesenteric injuries causing bowel ischemia will usually require segmental resection. Primary anastomosis is typically possible following jejunal and ileal resection for blunt intestinal injury. If anastamotic integrity is in question, a proximal diverting loop ostomy is performed as a temporizing measure while anastomotic healing takes place.

Early complications of blunt intestinal trauma include intraabdominal abscesses and prolonged ileus, which may necessitate parenteral nutrition. Late complications may manifest as

intestinal strictures or obstruction. The risk for developing small bowel obstructions appears to be highest in the first year following the traumatic injury.(93) Over the long-term, children with pancreaticoduodenal injuries are at risk for developing fistulas following operative repair, although this risk is reduced by pyloric-exclusion procedures.(94) Those children who undergo pyloric exclusion and those with anticipated need for prolonged bowel rest should have a jejunostomy feeding tube placed during the initial surgery to reduce the need for parenteral nutrition.

Grading of Evidence for the Treating of Traumatic Injuries of the Small Bowel in Children.

The majority of duodenal injuries, including intramural hematomas, may be non-operatively managed with nasogastric drainage, bowel rest, and serial abdominal examinations	1C/strong recommendation, low-quality or very low-quality evidence(74, 84, 91)
Injuries to the jejunum and ileum are managed operatively based on the extent of the injury. Small perforations can often be primarily repaired. Larger defects and mesenteric injuries causing bowel ischemia will usually require segmental resection	1C(84, 91)

Blunt Colonic Injuries

Traumatic injury of the colon is more commonly seen in cases of penetrating trauma; however, large bowel injury can result from blunt abdominal trauma in children. Blunt injuries to the colon more commonly occur in the transverse and ascending segments. (95, 96)

Children with blunt colonic injury may present with abdominal pain or abdominal wall ecchymosis (and/or the "lap belt complex"). Depending on the mechanism of injury and the presence or absence of concomitant injury, there may be few signs or symptoms suggestive of colonic damage upon initial presentation. Rectal examination is particularly useful in identifying distal colonic involvement and should be performed on every trauma patient. Testing stool for occult blood is generally not clinically relevant in the acute trauma setting, but an exam that is grossly positive for blood mandates anoproctoscopy.

Colonic injuries are often associated with intra-abdominal fecal contamination. In adults, the degree of fecal contamination correlates well with ultimate development of complications. (97) If large bowel injury is suspected, the entirety of the colon must be examined during exploratory laparotomy. This includes mobilization of the descending and ascending colon to inspect the posterior surface of the bowel.

Studies comparing primary repair (or resection with anastomosis) with diversion for traumatic blunt colonic injury have

not been performed in children. Historically, in adults, traumatic colonic injuries with fecal contamination were managed with exploratory laparotomy, intra-abdominal "washout," and colostomy for fecal stream diversion. The paradigm has changed in recent years, however, and primary repair or resection with anastomosis is now supported by the literature. Thorough irrigation of the abdominal cavity should be employed at the time of operation to reduce risk of intra-abdominal abscess development. When successful, intra-abdominal washout followed by primary repair eliminates the need for re-operation and the potential for stomal complications, in addition to lowering the financial and psychological burden of stoma care.

Grading of Evidence for the Treating of Traumatic Injuries of the Colon in Children.

Primary repair or resection with anastomosis following thorough irrigation of the abdominal cavity can be safely performed in children with blunt colonic injury	1C/strong recommendation, low-quality or very low-quality evidence (97)

Baby A's abdominal exam is closely monitored. His abdomen remains soft, non-tender, and non-distended. No additional abdominal imaging is warranted.

Intrapelvic Injuries from Blunt Trauma

Kidney

Due to its low positioning in the pelvis, lack of peri-nephric fat padding, and incomplete protection by the posterior ribs in children, the kidney is at risk for injury in situations of blunt abdominal trauma. In fact, blunt abdominal and flank trauma are the most common causes of renal injury in children.(98) Depending on how "injury" is defined (e.g., the presence of hematuria versus confirmed renal parenchymal injury), the incidence of renal injury due to blunt abdominal trauma is 10–22%.(99–101) The system for grading renal injuries is similar to that of other solid organ injury scales and is detailed in Table 22.5. The majority of traumatic renal injuries are low-grade and are amenable to non-operative management.(100)

Urinalysis to evaluate for the presence of hematuria should be part of the initial work-up, as renal injuries will typically present with hematuria, except in the rare situation of complete renal devascularization.(100, 102) Because FAST examination does not aid in the evaluation of renal parenchymal injuries, a full abdominal ultrasound, as performed by a radiologist, has been advocated as an initial imaging modality for the detection of such injuries, in children who do not otherwise require an abdominal CT scan. A formal ultrasound has the benefits of being a fast, reproducible test that can be performed without sedation and does not expose the child to ionizing radiation.(100) However, because ultrasound does not utilize contrast material, it is unable to evaluate renal perfusion and excretion, and may potentially miss a renal

Table 22.5 Classification of Traumatic Injury of the Kidney.

Grade	Kidney Injury
I	Contusion with significant hematuria No injury on imaging *Hematoma* Subcapsular or retroperitoneal hematoma without intraparenchymal laceration
II	No extravasation of urine *Hematoma* Restricted to the subcapsular or retroperitoneal regions *Laceration* Parenchymal tear < 1 cm; not involving collecting system
III	No extravasation of urine *Laceration* Parenchymal tear > 1 cm; not involving renal collecting system
IV	*Laceration* Extensive parenchymal injury and involvement of the renal collecting system *Vascular* Damage to the hilar vessels
V	Parenchymal destruction *Vascular* Hilar vascular injury with complete devascularization

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pedicle injury.(103) However, if the child has a renal injury, he or she is likely to require a CT scan for more complete abdominal evaluation, making the ultrasound redundant.

Imaging for renal injury in adult trauma patients is pursued if the patient presents with gross hematuria, shock, or history of significant deceleration injury or direct flank trauma. Whether these criteria should apply to children has been contested in the literature (87, 104, 105). Santucci et al. made the appropriate recommendation that "hypotension" should be replaced by "anemia" in pediatric trauma patients, as low hemoglobin is more predictive of on-going bleeding in children, due to the physiologic compensatory mechanisms that prevent hypotension in young patients even in the setting of significant blood loss.(102)

For those with suspected significant renal injury (based on clinical history, laboratory data, or ultrasound results), additional imaging is warranted. Abdominal and pelvic CT scanning with intravenous contrast enables evaluation of not only the potential parenchymal damage to the kidney but also any involvement of the urinary or vascular structures. Further, the injury grading scale for the kidney, as for the liver and spleen, is based on CT findings. Wessel et al. compared CT scanning with intravenous pyelography (IVP) and found CT to be superior for diagnosing Grade II–IV renal injuries; a reliable comparison for Grade I and Grade V injuries was not possible due to sample population size.(100) MRI angiography of the renal vasculature and collecting system is helpful for delineating collecting duct injuries suspected but not confirmed by CT scan.

Most renal injuries can be managed non-operatively with strict bed rest, bladder decompression via urethral catheter drainage, and close clinical observation. Successful non-operative management of even high-grade traumatic kidney injuries in children is attainable, although Grade V injuries will typically require operative repair. (99, 101, 106–109) Abdominal ultrasound can be used to evaluate for the development of peri-nephric hematoma or urinoma in children who develop symptoms, clinical evidence, or laboratory values consistent with on-going hemorrhage.(103)

Historically, urinary extravasation was a relative indication for operative intervention. However, children with a persistent urinary leak and urinoma can often be managed by percutaneous drainage, with complete resolution of the leak in the majority of patients. (101) Resolution of high-output leaks following percutaneous drain placement may be aided by ureteral stenting, although this can be technically challenging in young patients due to the relatively small caliber of the ureter in children.(101) These patients will often require definitive repair in the operating suite.

If active bleeding is identified in a symptomatic patient (i.e., pulsatile or expanding hematoma), operative exploration is indicated.(109) All attempts should be made to fully resuscitate and stabilize the patient prior to operative repair, as this increases the likelihood of successful parenchymal-preserving surgery. If pre-operative imaging (e.g., CT scan) was not obtained, an intra-operative pyelogram must be performed to both fully assess the extent of the injury and to confirm the presence of a functioning contralateral kidney.(110) Options for repair of blunt renal injuries include primary closure of lacerations with suture or fibrin glue, or partial nephrectomy. In cases of severe parenchymal damage (Grade V) or renovascular injury, total nephrectomy may sometimes be necessary. Kidney salvage following complete or near-complete devascularization of the organ is possible only if a revascularization procedure is performed within the first few hours following the injury.(111) A high-grade injury that is not repaired and results in kidney atrophy, carries a high likelihood that the child will develop hypertension.(111)

Following blunt renal trauma—regardless of whether operative or non-operative management was pursued—children are at long-term risk for loss of renal function due to atrophy or hypotrophy of the renal parenchyma.(111) Functional outcome appears to correlate with injury grade although true functional outcomes are difficult to assess, as most children do not undergo follow-up renal perfusion scanning (e.g., technetium-99m-dimercaptosuccinic acid scanning, DMSA scan).(112)

Grading of Evidence for the Treating of Traumatic Injuries of the Kidney in Children.

Urinalysis to evaluate for the presence of blood should be performed in all children with suspected blunt renal injury	1B/strong recommendation, moderate quality evidence(100, 102)
Most renal injuries can be managed non-operatively with strict bed rest, bladder decompression via urethral catheter drainage, and close clinical observation	1B(99, 101, 106–109)

Grade V injuries will typically require operative repair	1B(99, 101, 106–109)
Children with a persistent urinary leak and urinoma can often be managed by percutaneous drainage, with complete resolution of the leak in the majority of patients	1C/strong recommendation, low-quality or very low-quality evidence(101)
If active bleeding is identified in a symptomatic patient (i.e., pulsatile or expanding hematoma), operative exploration is indicated	1B(99, 101, 106–109, 111)

Table 22.6 Pelvic Fracture Classification System.

I	Intact pelvic ring
II	Single break in pelvic ring
III	Two breaks in pelvic ring
IV	Isolated fractures of the acetabulum
Multiple	Includes Types III; II & IV; and III & IV

Source: Key JA(133).

Adrenal Injuries

Traumatic adrenal hemorrhage occurs uncommonly in pediatric blunt trauma and is typically seen in the setting of multi-organ injuries, with the most common co-injury being hepatic trauma.(113) It is more often seen on the right side.(114) Adrenal injury in a pediatric trauma patient should prompt investigation for co-injury of the liver, kidney, spleen, and lower chest. Less severe adrenal injuries are often incidental findings on CT scan. In and of themselves, traumatic adrenal injuries are usually self-limiting and do not require operative intervention, although significant hemorrhage requiring blood transfusion is possible.(113)

Musculoskeletal Injuries

Rib Fractures

Due to the greater compliance of the pediatric chest wall, tremendous force is needed to cause rib fractures. As such, rib fractures in children are frequently a marker for more extensive injury. Children who sustain rib fractures following a blunt traumatic injury have a higher mortality than those without rib fractures and are also more likely to need hospitalization for their injuries.(115) The number of rib fractures has been shown to correlate with the likelihood of multi-system injuries and with overall mortality in pediatric blunt trauma patients.(115) Concomitant head injury in a child with rib fractures carried a 71% mortality in a study by Garcia that evaluated 2,080 pediatric trauma patients.(115) Isolated rib fractures are generally best managed supportively, with good analgesia (including epidural infusions for more extensive injuries), splinting, and pulmonary toilet being the mainstays of treatment.

Pelvic Fractures

Pelvic fracture is an injury associated with significant morbidity and mortality in the pediatric trauma patient as it is another indicator that a tremendous force was transmitted to the child. These patients often require intensive levels of care and are more likely to need operative intervention during their hospital course.(116) The complications associated with pelvic fractures are related to the number of fractures, pelvic disruption, and the mechanism of injury. Pelvic fractures are classified based on number of fractures and bony structures involved (Table 22.6). Interestingly, only about one-third of patients with pelvic fractures will have synchronous orthopedic injuries.(116)

Pelvic stability is assessed during the secondary survey, as described previously. The entire pelvis should be examined for areas of tenderness, ecchymoses, or abrasions. Blood at the urethral meatus or the presence of hematuria are nonspecific for pelvic fracture but should prompt further investigation into the integrity of the pelvis and possible ureteral, bladder, or urethral injury. Physical examination has a sensitivity of approximately 93% in detecting pelvic fractures in children.(117) The exceptions are Type IV and combination pelvic fractures, which can be detected on physical exam in nearly all cases.(116) In contrast, imaging by AP plain film of the pelvis has an 87% sensitivity for pelvic fractures in children.(117) Classic findings include widened pubic symphysis, separation of the sacroiliac joints, and a noncontiguous pelvic ring.

Emergent pelvic stabilization is required for hemodynamically unstable patients with suspected pelvic fracture. This can be accomplished in different ways with the common end point being improvement in bony stability to prevent further vascular injury. Pelvic stabilization kits are available for this function. If such a kit is not available, a large sheet can be folded and twisted to form a belt. This is then placed behind the child at the level of the hips and tied snugly in front.

Admission GCS, Revised Trauma Score (calculated based on GCS, systolic blood pressure, and respiratory rate), or need for blood transfusion or endotracheal intubation have not been shown to correlate with presence of pelvic fracture.(116) Children with multiple pelvic fractures are, however, more than twice as likely to require a blood transfusion, as described by Junkins et al.(116) Hypotension in a pediatric trauma patient that is not responsive to volume resuscitation should raise suspicion for undiagnosed pelvic injury with intrapelvic hemorrhage.

The risk of major hemorrhage is more likely in children with Type II and multiple pelvic fractures.(118, 119) Children with multiple fractures have an approximately 50% higher likelihood of requiring transfusion and are more likely to have associated intra-abdominal organ damage, when compared with those children with single pelvic fractures.(116) Children are less likely to die from vascular disruption due to pelvic fractures, in comparison to adults, with mortality rates of 5 and 17%, respectively.(116, 118–120)

In children with pelvic fractures and hemodynamic instability, despite fixation measures, intervention is warranted. If available, these children can often be managed with selective angioembolization in the interventional radiology suite or operative room. Operative exploration is mandated if this modality is unavailable, or if the child remains hemodynamically unstable despite percutaneous intervention.

> Baby A's rib fractures are managed with oral and intravenous pain medications. The infant's parents are informed about the results of the initial testing and the need for admission for observation. In further discussions with the parents, their stories provide some conflicting information about the mechanism of injury. The child is admitted to the hospital and the social services consultants are informed. A skeletal series performed on hospital day 2 reveals healed fractures in the left arm, multiple ribs, and lower legs.

THE BATTERED CHILD—SOCIAL, LEGAL, AND CLINICAL ASPECTS

The Statistics of Child Abuse

The problem of child abuse is staggering. In 1993 alone, 3 million reports of child abuse were made; a harrowing thought given that most experts agree child abuse is markedly underreported.(121) Every year approximately 160,000 children sustain severe or life-threatening injuries as a result of abuse, from which 1,000–2,000 children will die.(122) Figure 22.3 details the multifactorial pathway of risk factor attenuation that contributes to child abuse. While poverty is the most noted and most consistent of all risk factors for abuse, abuse occurs across all socio-economic strata and every child must be screened for potential abuse.(121)

Evaluating for Child Abuse in a Pediatri Blunt Trauma Patient

The abused child may present with a wide spectrum of injury, from superficial abrasions and bruising, to intra-abdominal trauma, to major head injury. Major blunt abdominal trauma due to inflicted injury is a serious condition that carries a mortality rate of 50%.(123) Being able to identify trauma patients whose injuries were intentionally inflicted is of significant importance. History—including mechanism of injury—is an important clue in deciphering inflicted versus accidental trauma and particular note should be made of histories that are inconsistent with patient development (e.g., a 5-month-old infant who fell climbing out of her crib). Co-injuries such as soft-tissue trauma (i.e., hematoma), head trauma, and bony/skull fractures, in conjunction with abdominal trauma, should prompt further investigation into the possibility of non-accidental injury.(123) Children with combined hollow viscus and solid organ injury are more likely to have sustained their injuries from inflicted injury.(124) A delay in presentation for treatment is often seen in children who have been physically abused, although this is not specific.(124)

Physical exam is also very important in identifying physical abuse. Careful documentation of the findings is critical in the
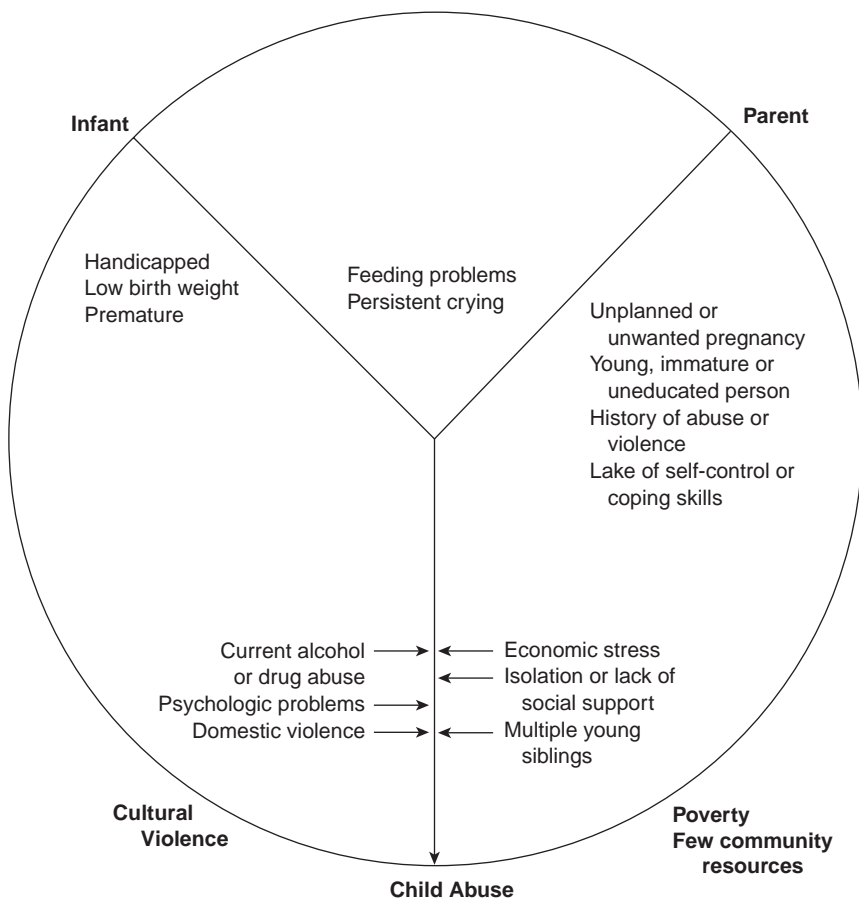
Figure 22 3 Factors contributing to child abuse.

Source: Bethea L (121), with permission.

management of the abused child. Patterned burns and burns in unusual areas should raise suspicion for abuse and can shed important clues. It should be remembered that bruises in otherwise healthy children less than 9 months old are very rarely accidental.(125) A study by Sugar demonstrated that bruising related to walking in toddlers is typically found on the anterior tibia or knee, and the forehead; less than 2% of toddlers had forearm bruises related to walking.(125) Bruising of the trunk, thighs, and upper arms is particularly concerning for non-accidental trauma. Unusual burn patterns should also raise a flag for child abuse and include very sharply-defined burn margins and burns to the buttocks and perineum. Additionally, traumatic injuries, bruising, or burns to the peri-orbital or perineal area are often associated with child abuse. Retinal hemorrhage or multiple subdural hematomas without concurrent skull fracture are worrisome for shaking injury and require further evaluation into mechanism of injury.

A skeletal plain film series should be performed on any child with suspected inflicted injury. The presence of rib fractures, long bone fractures in children under age 3, or evidence of fractures in various stages of healing are highly suspicious for child abuse. (126) CT scan is often necessary to evaluate for intracerebral and intra-abdominal pathology in these children. An ophthalmologic exam, to identify retinal hemorrhages, is also a valuable component of the physical exam in cases of suspected abuse.

Legal Issues Involving Physicians and Suspected Child Abuse

Physicians are required by law, in every state, to report suspected child abuse or neglect. Physicians who report abuse based on a reasonable accounting of facts, clinical data, or history, are subsequently immune to civil or criminal charges. However, a physician who suspects abuse and fails to report the findings *is* subject to both criminal and civil charges.

Children with suspected intentionally inflicted injuries should be admitted to the hospital for further investigation. Social services should be contacted immediately as they will be a liaison to legal authorities and will assist in finding temporary placement of the child, should this be necessary. Whether to inform the caregivers of the ensuing investigation is the decision of the physician, but one that should be made in conjunction with a social services representative, as the potential harm to other children in the patient's home may be of issue.

INJURY PREVENTION

Car seats

Children younger than 4 years old and those less than 40 pounds should be restrained in NHTSA-approved car seats every time they travel in a motor vehicle. These seats should be installed rear-facing until the child reaches, at minimum, 1 year of age *and* 20 pounds in weight, after which time the car seat can be secured in a forward-facing direction. Ideally, children of all ages should sit in the back seat. If rear seating is not available, children should be appropriately restrained in the front seat and the passenger-side air bag should be disengaged (if possible). Rear-facing car seats should never be placed in the front passenger seat of automobiles with passenger-side air bags.(127)

Children heavier than 40 pounds who have outgrown forward-facing car seats should transition to a booster seat until they are taller than 4'9".(127) The booster seat facilitates proper fitting of the seat belt across the upper thigh and chest. The "lap belt complex," as described previously, is most common in children who are too large for traditional car seats but too small for standard lap belt restraint systems. When the lap belt is placed on a small child not in a booster seat, it is often improperly positioned over the intra-abdominal organs, without the protection of the bony pelvis. In collisions, these organs are compressed between the seat belt and the spine, potentially causing intra-abdominal injury. This can be avoided by the use of a booster seat.

Bicycle Safety

The safety of children riding on bicycles is ensured through a multifaceted approach that centers on education of children, parents and caregivers, and motorists. Public health campaigns encouraging the use of appropriately sized helmets for all bicyclists have increased their use over the past 10 years. Helmets should fit snugly onto the child's head and extend over the forehead to a level approximately two finger-breadths above the eyebrows. Side and chin straps should be snug to prevent movement of the helmet after an impact. It is important that parents buy a helmet that fits the child *now,* not one that he or she will "grow into." In addition to ensuring a properly fitted helmet, parents and caregivers should also be instructed to inspect their child's bicycle on a frequent basis for the presence of loose or broken parts that could cause injury to the child or precipitate a fall or crash. Similar protective measures should be used for other "high speed" activities, such as in-line skating or riding scooters. In addition to a helmet, the use of wrist, elbow, and knee guards can help minimize potential injuries.

> Baby A is admitted to the inpatient service for observation. He is seen and treated by the pediatric orthopedics service for bilateral femur fractures. He remains hemodynamically stable throughout his hospitalization. Serial abdominal examinations are performed and the child's distention and tenderness improves over the first 36 h of hospitalization. After ensuring that the child is pain-free and tolerating regular feedings, he is discharged to a court-appointed foster family home as child protective service completes their investigation into the trauma.

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23 Blunt trauma in pregnancy

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A 27-year-old restrained driver is admitted to the Emergency Room (ER) after she was hit on her side of the vehicle by a pickup truck. She denies any past medical history but reports that she is 28 weeks pregnant. In the field, she was immobilized in a cervical collar and placed supine on a long spine board. On arrival in the ER, she is awake and alert and complaining of abdominal pain; she is concerned that she has not felt her baby move since the accident. Primary survey is unremarkable except for a heart rate of 110. She receives a bolus of saline and is placed on oxygen. As the secondary survey is initiated, the patient's blood pressure drops to 90/60 mmHg with a heart rate of 130 bpm. With a bolus of an additional liter of fluid and manual displacement of the gravid uterus to the left, the blood pressure increases to 110/70 mmHg and the pulse returns to 110 bpm. Focused assessment for the sonographic examination of the trauma patient (FAST) is negative. The secondary survey is remarkable for left-sided chest wall ecchymosis, abdominal pain which appears to be most severe over the uterus and tenderness of the bony pelvis. The obstetrician arrives in the ER. Fetal ultrasound demonstrates a fetal heart rate of 140 and no abruption is noted. The patient is placed on continuous fetal monitoring. A pelvic exam is conducted; the cervix is closed and there is no blood noted at the os. In addition to a type and cross an arterial blood gas (ABG) is obtained as well as labs for placental abruption. The ABG reveals a base deficit of 8 and hemoglobin of 8. Supine anterior posterior (AP) chest X-ray, performed with care taken to shield the uterus, shows fractures of ribs two through five on the left with underlying pulmonary contusion. AP pelvis X-ray demonstrates left superior and inferior pubic rami fractures. The patient again experiences a decline in her systolic blood pressure. Repeat FAST examination demonstrates fluid in the splenorenal window and the patient is taken emergently to the operating room. She is intubated without complications and undergoes an uncomplicated exploratory laparotomy with a splenectomy for a shattered spleen. The uterus is examined intraoperatively and noted to be uninjured. Fetal heart tones are normal. After consultation with the obstetrician, the abdomen is closed. Postoperatively the patient is transferred to the intensive care unit where continuous fetal monitoring is resumed. She has an uneventful hospital course and is discharged home on post-operative day 7, non-weight bearing on the left secondary to the pelvic fractures. The remainder of the pregnancy is uncomplicated and the patient undergoes a spontaneous vaginal delivery of a healthy infant at term.

DEMOGRAPHICS

An estimated 5 to 8% of all pregnancies are complicated by trauma and it is the leading cause of non-obstetric related maternal deaths (1–3). One study found that trauma was responsible for 46.3% of deaths in pregnant women.(4, 5) Maternal trauma is associated with significant fetal morbidity and mortality (6, 7); estimates of fetal death rates following trauma vary widely ranging from 4 to 61% of cases.(1) Risk factors associated with fetal loss include high maternal injury severity score and shock in the mother (4) Although fetal loss may be more common with increasing maternal injury, both major and minor maternal injuries have resulted in spontaneous abortion, premature labor and delivery, fetal hypoxia, fetal skull fractures, uterine rupture, placental abruption, and maternal fetal hemorrhage.(2, 8–11)

The most common mechanism of maternal injury is motor vehicle collision, accounting for approximately 55% of maternal trauma (2); falls and physical abuse account for an additional 10 to 31% of injuries.(12, 13) Motor vehicle crashes (MVC) have been shown to be the leading cause of fetal death related to maternal trauma; an examination of fetal death certificates found that MVCs are responsible for 82% of fetal deaths associated with maternal trauma.(14)

> The patient suffered a significant mechanism of injury and both the patient and her fetus are at risk.

ANATOMY AND PHYSIOLOGY

Anatomy

Early in the gestational period, the fetus is well protected in the uterus which lies within the pelvis. After the 12th week, the uterus begins to expand out of the pelvis and into the abdomen reaching the umbilicus at 20 weeks gestational age and the costal margin at 36 weeks.(12, 15) In the final 4 weeks, the fetus descends into the pelvis and fundal height is lower. As pregnancy advances, maternal organs are displaced upward and the diaphragm may be elevated as much as 4 cm from the nonpregnant state. While the gravid uterus may provide a degree of protection to the maternal viscera, the fetus is at increased risk of direct injury as the pregnancy progresses. In the third trimester, the uterine wall thins, the amount of amniotic fluid decreases, and the fetal head rotates down and into the pelvis all of which place the fetus at increased risk for injury.(12, 15–16) In particular, the location of the fetal head within the pelvis places the fetus at risk of skull fractures and traumatic brain injury secondary to maternal pelvic fractures.

Maternal Physiology

Pregnancy results in dramatic changes in maternal physiology affecting virtually every organ system. Only those changes

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particularly relevant to management of the pregnant trauma patient will be discussed.

Over the course of a normal pregnancy, there is an increase of maternal total body water of 6.5–8.5 l. The water content of the fetus, placenta, and amniotic fluid accounts for 3.5 l. Maternal blood volume is expanded by approximately 1,500 mL, plasma volume by 1,200 mL, and red blood cell volume by 300–400 mL. Because the plasma volume expands more than red blood cell mass, the result is a physiologic anemia of pregnancy.(16) The increased blood volume protects the mother from hemorrhage and hypotension. As a result, the presence of hypotension in the pregnant patient indicates a significant volume loss and should be addressed promptly. The vasculature of the placenta is dilated at baseline, but very responsive to catecholamines. A decrease in maternal circulating volume and catecholamine release may result in a significant increase in uterine vascular resistance, diminished placental blood flow, and a reduction in fetal oxygenation even in the presence of normal maternal vital signs.(15) In fact, maternal volume loss may first be manifested as fetal distress.(12)

Pregnancy results in profound changes in the cardiovascular system. Cardiac output is significantly increased in pregnancy by an average of 30 to 50% as compared to the nonpregnant state. Cardiac output is the product of stroke volume and heart rate and both of these parameters are altered in pregnancy. There is an initial rise in maternal heart rate (HR) at about 5 weeks; the HR continues to increase until about the 32nd week when it peaks at 15–20 beats per minute above the patient's pregravid state. Stroke volume begins to increase at 8 weeks and at 32 weeks it reaches a maximum value of 20 to 30% increase over pre-pregnant values. While cardiac output is increased in pregnancy, it is highly variable with respect to maternal position, particularly with advanced pregnancy. In late pregnancy, the gravid uterus may completely occlude the vena cava when the patient is in the supine position, dramatically reducing venous return, stroke volume, and as a result, cardiac output.(16) Venous return and, therefore, cardiac output are optimized when the pregnant patient is in the left lateral position with the knees brought toward the chest to alleviate the compression of the inferior vena cava.

The respiratory system also undergoes a significant change in the course of pregnancy. The upper respiratory tract becomes hyperemic and edematous.(16) Care should be taken when placing nasogastric tubes in pregnant patients to avoid excessive bleeding. The chest wall undergoes reconfiguration as the subcostal angle increases and the chest circumference expands by 5–7 cm. The level of the diaphragm rises 4 cm, decreasing the volume of the lungs in the resting state, reducing both total lung capacity and functional residual capacity (FRC). As a result of the decreased FRC, there is a 5 to 10% increase in the inspiratory capacity. The vital capacity, however, remains the same. Pregnancy also is a state of chronic hyperventilation with a 30 to 40% increase in minute ventilation driven by an increase in tidal volume. As a result, the arterial paCO2 is decreased. Whereas a normal paCO2 is generally considered to be 37–40 mmHg, in the pregnant patient the expected paCO2 is 27–32 mmHg creating a chronic respiratory alkalosis. Increased maternal excretion of bicarbonate lowers the serum bicarbonate levels to 18–21 meq/L and maintains the maternal pH between 7.4 and 7.45 with a

partial renal compensation. The decrease in maternal paCO2 results in a gradient between maternal and fetal CO2 that facilitates the transfer of CO2 from the fetal to maternal circulation for excretion. It is of the utmost importance to avoid acidosis in the pregnant patient as maternal acidosis compromises fetal–maternal gas exchange.(16)

In addition to the increased red cell mass as noted above, there are other changes in the hematologic system in the pregnant patient. The peripheral white blood cell count (WBC) rises throughout pregnancy. In the first trimester normal values range from 5,110 to 9,900/mm^3, but in the second and third trimesters the range varies from 5,600 to 12,200/mm^3. In labor, a WBC in the range of 20,00 to 30,000/mm^3 is not unusual. Additionally, changes occur to protect against peripartum hemorrhage, the etiology of which is multifactorial. Various procoagulants are increased and changes occur to some of the inhibitors of coagulation. There is also decreased activity in the fibrinolytic system with reduced levels of plasminogen activator.(16) Consequently, pregnancy is a hypercoaguable state and the pregnant trauma patient is at increased for venous thromboembolic complications.

Glucose metabolism is altered during pregnancy. The changes in carbohydrate metabolism result in fasting hypoglycemia, postprandial hyperglycemia, and hyperinsulinemia. "In normal pregnancy, maternal fasting is characterized by accelerated starvation. (16) The constant demands of the fetal–placental unit for glucose results in early depletion of maternal glycogen stores with fasting and a rapid conversion from carbohydrate to fat utilization. In the fed state, insulin resistance begins in the first trimester. In the normal pregnancy, the pancreas compensates with an exaggerated insulin response. If the patient has limited pancreatic reserve in the pre-pregnant state, then patient may not produce enough insulin to overcome the resistance resulting in gestational diabetes. As the fetus is primarily dependent on maternal glucose, normal maternal glucose levels are critical for proper fetal development. Hyperglycemia in the first trimester is associated with birth defects and in the third trimester with fetal macrosomia. (16) Normal blood glucose levels should be maintained in the pregnant trauma patient to optimize maternal–fetal outcome.

Finally, while there are alterations throughout the gastrointestinal tract in pregnancy, changes to the esophagus and stomach are noteworthy. The lower esophageal sphincter has diminished tone and both gastric tone and motility are reduced in pregnancy. (16) Consequently, the pregnant patient is at risk for aspiration and early gastric decompression should be considered, especially prior to intubating the injured pregnant patient.(12)

> The presence of hypotension and tachycardia in the patient suggest that a significant volume loss has occurred in the mother.

INITIAL RESUSCITATION AND ASSESSMENT

Primary Survey

One of the leading causes of fetal demise following trauma is maternal demise.(10, 12) Therefore, the primary focus on the

initial assessment must be the prompt evaluation and treatment of the mother following the guidelines as outlined in the American College of Surgeons Committee on Trauma Advanced Trauma Life Support manual. As a result of the anatomic and physiologic changes that occur during pregnancy, there are a few special considerations in the primary survey. The decreased gastric motility places a pregnant woman at increased risk for aspiration and early gastric decompression is appropriate. Because the fetus is sensitive to maternal hypoxia, supplemental oxygen should be provided. Additional care should also be taken during intubation. If rapid sequence intubation is employed, a lower dose of succinylcholine is required due to decreased pseudocholinesterase levels in pregnancy.(13) If a tube thoracostomy is required, it should be placed one or two intercostal spaces higher than in nonpregnant patients secondary to the diaphragm elevation. It is especially helpful to use the sagittal thoracic ultrasound examination to identify the location of the diaphragm. (17) Finally, compression of the vena cava by the gravid uterus and resultant hypotension can be minimized by either manually displacing the gravid uterus to the left or tilting the long spine board to the left.(18) A focused abdominal ultrasound examination should be performed to evaluate the mother for intraperitoneal hemorrhage. (13) A focused abdominal ultrasound in pregnant trauma patients has been found to detect intraperitoneal fluid with a sensitivity, specificity, and accuracy similar to that of nonpregnant patients.(19) As an alternative to ultrasound in the unstable patient, a diagnostic peritoneal lavage can also be performed using the open technique with a suprapubic incision.(13)

> The patient was originally hypotensive and tachycardic on arrival to the trauma bay. Displacement of the uterus to the left alleviated compression on the inferior vena cava, improving venous return, and maternal blood pressure.

Fetal Assessment

After the primary survey is completed and all immediately life-threatening issues addressed in the mother, it is appropriate to perform a fetal assessment and consider monitoring. An estimated gestational age of 20–24 weeks should prompt uterine and fetal monitoring under the supervision of the obstetric service. (2, 13) If the mother is unable to provide obstetric history, the fundal height can be used as an estimation of gestational age. In general, if the fundus is at the level of the umbilicus, the gestational age is at least 20 weeks and it should be assumed that the pregnancy is viable until an obstetrician determines otherwise. Cardiotocographic monitoring should be initiated as soon as possible and preferably immediately following the secondary survey in all potentially viable pregnancies. The monitoring should be in place for a minimum of 2–6 h and the duration of monitoring should be increased in all patients with abdominal pain, contractions, or significant maternal injury.(13)

Ideally, the obstetrician or maternal fetal medicine specialist will be involved early in the care of these patients and be present to perform the initial fetal assessment. The fetal ultrasound examination should include fetal heart rate and position, assessment of gestational age, biophysical profile, fetal middle cerebral artery Doppler examination, and evaluation of the placenta for

abruption.(13) Normal fetal heart rate varies between 120 and 160 bpm; both fetal bradycardia and tachycardia may have great clinical importance.(20) It is important to note that ultrasound has a sensitivity of about 50% for placental abruption; however, the positive predictive value of the test is high.(13) If abruption is suspected and there is evidence of fetal compromise in a viable gestation, emergent operative delivery should be considered.(2)

> An obstetrician evaluated the patient in the trauma bay. The fetus was in no distress as evidence by a reassuring fetal heart rate. Monitoring was initiated. Evaluation and resuscitation of the mother were continued appropriately.

Secondary Survey

The secondary survey of the mother is then performed followed by definitive care of both maternal and fetal injuries. In the pregnant patient, the secondary survey must include a vaginal examination to assess for cervical effacement and dilation, fetal position as well as for the presence of blood or amniotic fluid. Vaginal bleeding is abnormal and may be a sign of labor, placental abruption, placenta previa, or uterine rupture.(2, 13)

> Vaginal examination demonstrated a closed cervix, no dilation, and no blood.

Laboratory Evaluation

All laboratory studies routinely ordered in trauma patients should also be obtained in the pregnant patient. At a minimum this should include hemoglobin, hematocrit, coagulation profile including fibrinogen, and type and cross-matching. Patients with a significant mechanism of injury and hemodynamic instability should also have an arterial blood gas assessed. In addition, the Kleihauer–Betke (KB) test should be obtained in all Rh-negative women to ascertain whether fetal blood has entered the maternal circulation.(2) Any Rh-negative woman with a positive test should receive Rh-immune globulin. The initial dose is 300 μg followed by 300 μg for each 30 mL of estimated fetomaternal transfusion.(2, 13) Recent data have also suggested that the KB test is an accurate predictor of the risk of preterm labor following maternal trauma. In a retrospective review, Meunch et al. found that a positive KB test was a sensitive way to detect preterm labor and conversely, a negative KB test excluded preterm labor. These authors and others now recommend KB testing in all pregnant trauma patients.(21)

Imaging

Imaging studies should be obtained in the pregnant patient for the same indications as they are performed in the nonpregnant patient. While various adverse effects on the fetus including microcephaly and mental retardation have been noted with high-dose radiation, no increase in teratogenicity for a fetus exposed to less than 10-rad or 100-mGy of radiation has ever been documented. (13) The American College of Obstetricians and Gynecologists has published guidelines for imaging during pregnancy and state that a

5-rad or 50-mGy exposure is not associated with adverse fetal outcome.(13) Shields such as a lead apron should always be employed when possible as they reduce the radiation exposure of the fetus by 30%. Table 23.1 lists the radiation exposure to the unshielded fetus for various imaging studies. If the patient is severely injured and multiple imaging studies are anticipated, it may be reasonable to consult a radiation specialist to assist in planning. Furthermore, a radiation dosimeter badge may be attached to the mother so that the radiation dose may be easily tracked. This badge may be very helpful in those patients who are admitted to the intensive care unit and may need daily chest radiographs or other frequent studies.(13) Pregnancy alone, however, should not deter the physician from ordering necessary diagnostic and therapeutic tests. In fact, successful selective angioembolization of a bleeding spleen has been reported in a multiply injured woman who was early in her second trimester with a successful fetal outcome.(22)

> Indicated radiographic studies were performed in our patient with appropriate shielding of the gravid uterus.

Table 23.1 Radiation Exposure to an Unshielded Uterus.

Imaging Study	Uterine radiation dose (rads)	Uterine radiation dose in milligray (mGy)
Plain film		
Abdomen (AP)	0.133–0.92	1.33–9.2
Abdomen (PA)	0.064–0.3	0.64–3
Cervical spine	Undetectable	Undetectable
Chest (AP)	0.0003–0.0043	0.003–0.043
Chest (PA)	< 0.001	< 0.01
Femur	0.0016–0.012	0.016–0.12
Hip (AP)	0.01–0.21	0.1–2.1
Pelvis (AP)	0.142–2.2	1.42–22
Full spine (AP)	0.154–0.527	1.54–5.27
Lumbar spine (AP)	0.031–4.0	0.31–40
Thoracic spine (AP)	< 0.001	< 0.01
Computed tomography		
Upper abdomen	3.0–3.5	30–35
Entire abdomen*	2.8–4.6	28–46
Head	< 0.05	< 0.5
Pelvis*	1.94–5.0	19.4–50
Thorax	0.01–0.59	0.1–5.9

AP, anteroposterior; PA, posteroanterior. Shielding reduces exposure by 30%. Reprinted from Obstetrics and Gynecology Clinics of North America, 34(3); Meunch MV and Canterino JC; Trauma in Pregnancy, 566, 2007; with permission from Elsevier.
*Depends on trimester.

INTRAOPERATIVE MANAGEMENT

Indications for Laparotomy

The indications for laparotomy in the pregnant trauma patient remain the same as for the nonpregnant trauma patient. These include hypotension in the presence of intraperitoneal fluid detected on ultrasound, peritonitis, and failed nonoperative management of solid organ injury. During laparotomy, the obstetrician should be present and if delivery of the fetus is anticipated, a neonatologist should also be immediately available as well as the resources to resuscitate the infant.

Anesthesia in the Pregnant Patient

As mentioned previously, the pregnant patient should be considered at high risk for aspiration. Intubation should be conducted by the anesthesiologist as expeditiously as possible using rapid sequence intubation with cricoid pressure. Pregnancy alters the anatomy of the airway and the larynx is pushed anteriorly. The need to maintain inline cervical immobilization and friable, edematous oral, nasal and tracheal mucosa that is prone to bleeding may further complicate the intubation. Pregnant trauma patients should be considered to have "difficult" airways until proven otherwise and it is advisable to have a "difficult" airway cart equipped with a flexible fiberoptic bronchoscope in the room.(23) The trauma surgeon should be present during the induction of anesthesia to perform an emergent surgical airway if needed as the fetus is especially sensitive to hypoxia. Once the patient is intubated, she should be slightly hyperventilated to a pH of 7.4–7.45 to mimic the normal physiology of pregnancy.(23)

Thiopental or etomidate are useful induction agents. Ketamine should be avoided as it causes increased uterine tone and decreased uteroplacental perfusion. As noted previously, smaller doses of succinylcholine are required in pregnant patients. Both depolarizing and nondepolarizing neuromuscular blocking agents cross the placenta and can result in hypotonic and apneic infants for which the neonatal resuscitation team must be prepared. If the patient can tolerate a volatile anesthetic, one should be used as these agents relax uterine smooth muscle and decrease circulating catecholamines thus improving uterine perfusion.(23)

Technical Considerations

Following the induction of anesthesia, a fetal monitor should be placed by the obstetrician if indicated. If the planned incision makes intraoperative monitoring of the fetus impossible, then, at a minimum, fetal heart rate should be measured immediately before and at the termination of the procedure. A wedge should be placed under the patient s right side to displace the uterus and avoid inferior vena cava compression while maintaining spinal precautions. Ongoing resuscitation should be provided as it would be for any other trauma patient. If available, cell salvage devices may be utilized for volume replacement provided that a leukocyte depletion filter is employed. Waters et al. has demonstrated that the risk of amniotic fluid embolus is low when using this technique.(23, 24) Laparotomy is carried out though a vertical midline incision in the standard fashion and all indicated procedures are performed. If the uterus is found to be intact at laparotomy and the fetus is not in distress, intraoperative

delivery is rarely indicated. On rare occasion, intraoperative delivery may be indicated to expose and control nonobstetric-related hemorrhage in the mother.(25)

INJURIES UNIQUE TO THE PREGNANT TRAUMA PATIENT

Placental Abruption

The vast majority of fetal losses following blunt trauma to the abdomen are the result of placental abruption. Although the reported incidence of abruption in patients with minor injuries is 1 to 5%, it is estimated to occur in 40 to 50% of significant maternal trauma.(4) Further, it is estimated to cause over 70% of fetal losses following blunt abdominal trauma.(2, 15) While the uterus has a great deal of elasticity, the placenta does not. In blunt trauma, shearing forces occur at the uterine–placental interface resulting in separation of the placenta.(15) Patients present with vaginal bleeding, abdominal pain, uterine irritability as seen on fetal monitoring, shock, or fetal distress. It should be noted that abruption can occur in the absence of significant uterine bleeding.(15) The only treatment for a significant abruption is immediate delivery of the fetus.

Preterm Labor

There is about a 5% incidence of preterm labor following maternal trauma. Labor is initiated following trauma by one of two mechanisms: either premature rupture of the membranes or destabilization of lysosomal enzymes resulting in prostaglandin production.(15) If the membranes are intact, tocolytic therapy should be considered if deemed appropriate by the treating obstetrician.

Uterine Rupture

Uterine rupture is a rare, catastrophic complication of blunt abdominal trauma. The incidence is approximately 0.6% of cases of all blunt trauma during pregnancy.(2) Occurring primarily late in pregnancy, the fetal mortality approaches 100% with a maternal death rate of 10% from associated injuries.(15)

Direct Fetal Injury

Direct fetal injury is very rare in blunt trauma complicating less than 1% of all significant maternal trauma.(2, 13, 15) The maternal soft tissue, uterus, and amniotic fluid all provide a significant degree of protection to the fetus. Those cases of direct fetal injury that do occur are usually late in the gestational period. The most commonly reported direct fetal injury is head injury. If the head of the fetus is engaged in the pelvis, the fetus is at increased risk for brain and skull injuries.(15) Even if the head is not engaged, the fetus is at risk for shearing injury to the brain. Overall, pelvic fractures are the most common specific maternal injury resulting in fetal mortality.(2) Of note, pelvic fractures are not an absolute contraindication to vaginal delivery.(13) Women who have suffered a pelvic fracture are, however, more likely to require an operative delivery than women that have not suffered a pelvic fracture. Severe traumatic fetal brain injury secondary to airbag deployment has also been reported.(10)

Emergency Cesarean Section

Indications for emergency operative delivery include a potentially viable fetus by gestational age, the presence of fetal heart tones, maternal distress, or fetal distress. A multicenter study documented infant survival rate of 75% of potentially viable gestations that underwent emergent operative delivery. (26) The obstetrician, if available, should be involved in the decision-making process.

Perimortem Section

Perimortem section should be considered in the case of maternal arrest with a potentially viable fetus. Delay in recognition of fetal distress is a preventable cause of fetal demise.(26) The best fetal outcomes have been documented if the infant is delivered within 5 minutes of the cardiovascular collapse of the mother. This leaves very little time for decision making. Factors that should be considered include the estimated gestational age of the fetus and the resources available at the hospital.(13) A vertical midline incision should be used from the xiphoid to the pubic symphysis. The uterus is incised vertically and opened. The umbilical cord is clamped and cut and resuscitation of the neonate is initiated. Maternal resuscitative efforts should be carried out simulataneously.(26)

Fetal Outcome

About 80% of women who suffer trauma during their pregnancy are released from the hospital without requiring delivery of the fetus.(8, 27) Several studies have been published that suggest that injuries during pregnancy are associated with increased risk of both maternal and fetal adverse outcomes at the time of eventual delivery. These include prematurity, low birth weight, fetal distress, and requirement of transfusion at delivery.(27) The etiology for these adverse outcomes may be related to subclinical abruption at the time of trauma. Other studies have contradicted this and suggested that in the absence of complications at the time immediately surrounding the trauma, there is no difference in pregnancy outcome as assessed by Apgar scores, birth weight, gestational, or age at time of delivery between injured and non-injured patients.(4) Regardless, if the pregnant trauma patient leaves the hospital undelivered, the trauma and sequalae should be directly communicated to the patient s obstetrician to allow for additional assessment and care during the remainder of the pregnancy and delivery if indicated.

> The patient underwent an uneventful vaginal delivery of a term infant.

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First Author	Year	Reference Title	Grade	Summary
Patteson SK	2007	The Consequences of High-Risk Behaviors: Trauma During Pregnancy. J Trauma 2007; 62: 1015–20	2B	Retrospective case-control. A high percentage of pregnant trauma patients engage in risk behaviors. Pregnant trauma patients may be at higher risk of fatality compared to nonpregnant patients.
Shah KH	1998	Trauma in Pregnancy: Maternal and Fetal Outcomes. J Trauma 1998; 45(1): 83–96	2B	Retrospective case-control analysis of injury pregnant patients. Maternal death, high ISS, serious abdominal injury and shock risk factors for fetal death. Significant role for the implementation of preventative strategies.
Fildes J	1992	Trauma: the leading cause of maternal death. J Trauma. 1992; 32: 643–645	2B	Retrospective review of county medical examiner records. Trauma was the leading cause of maternal death, accounting for 46.3% of maternal deaths.
Sperry JL	2006	Long-term fetal outcomes in pregnant trauma patients. Am J Surg 2006; 192: 715–21	1B	Retrospective cohort study of pregnant trauma patients. A history of trauma during gestation is associated with preterm delivery and low birth weight. These patients should be considered "high risk" obstetric patients.
Ikossi DG	2005	Profile of Mothers at Risk: An Analysis of Injury and Pregnancy Loss in 1,195 Trauma Patients. J Am Coll Surg 2005; 200(1): 49–56	1B	NTDB study of 1195 pregnant trauma patients. Young, African-American and Hispanic women are at higher risk for trauma in pregnancy and are most likely to benefit from primary prevention. Reductions of secondary insult and early recognition of fetal distress may improve outcome.
Schiff MA	2005	Pregnancy outcomes following hospitalization for motor vehicle crashes in Washington state from 1989 to 2001. Am J Epidemiol 2005; 161: 503–10	1B	Retrospective cohort study. Pregnant patients hospitalized following MVCs are at significant risk for adverse pregnancy outcomes; monitoring is warranted.
Farmer DL	1990	Fetal trauma: relation to maternal injury. J Pediatr Surg 1990; 25(7): 711–4	2C	Retrospective review of 32 cases. Found that extent of maternal injury does not necessarily correlate with degree of fetal injury. Fetal loss can occur in the absence of significant maternal trauma
Karimi P	2004	Extensive brain injury in a premature infant following a relatively minor maternal motor vehicle accident with airbag deployment. J Perinatol 2004; 24(7): 454–7	2C	Isolated case report of fetal injury putatively related to airbag deployment.
Stafford PA	1988	Lethal intrauterine fetal trauma. Am J Obstet Gynecol 1988; 159(2): 485–9	2C	Case series of 8 patients with lethal intrauterine injuries. Lethal injury to the fetus can occur in absence of significant maternal trauma.
Weiss HB	2001	Fetal deaths related to maternal injury. JAMA 2001; *286(15): 1863–8*	1B	Retrospective review of fetal death certificates determined that MVCs are the leading cause of fetal death related to maternal trauma. Recommends improved tracking of fetal death.
Rozycki GS	2001	Surgeon-performed ultrasound in the critical care setting: its use as an extension of the physical examination to detect pleural effusion. J Trauma 2001; 50: 636–42	2B	Surgeon performed ultrasound can assist in the diagnosis and treatment of pleural effusion.
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Muench MV	2004	Kleihauer-Betke testing is important in all cases of maternal trauma. J Trauma 2004; 57(5): 1094–8	1C	Retrospective review which found that KB testing predicted risk of preterm labor. Advocated KB testing in all pregnant trauma patients.
Muench MV	2004	Successful pregnancy outcome after splenic artery embolization for blunt maternal trauma. J Trauma 2004; 56(5): 1146–8	2C	Isolated case report of successful pregnancy outcome after selective splenic artery embolization following blunt maternal trauma.
Waters JH	2000	Amniotic fluid removal during cell salvage in the cesarean section patient. Anesthesiology 2000; 92: 1531–6	2C	Prospective study of 15 nonlaboring pregnant women found that leukocyte depletion filtering of cell-salvaged blood obtained from cesarean section reduces particulate contaminants to a concentration equivalent to maternal venous blood. May reduce risk of amniotic fluid embolism.
Morris JA Jr	1996	Infant survival after cesarean section for trauma. Ann Surg 1996; 223(5): 481–8	2B	Multi-institutional retrospective cohort study found acceptable survival (75%) in viable infants following emergency cesarean section. Delay in recognition of fetal distress and cesarean section associated with increased mortality.

24 Acute respiratory failure
Randall Friese

A 60-year-old man with longstanding chronic obstructive pulmonary disease (COPD) sustains a left flail chest in a motor vehicle crash. He is admitted to the hospital for pain control and pulmonary hygiene. On hospital day 3, he is transferred to the surgical intensive care unit for tachypnea and complaint of feeling short of breath. Arterial blood gas analysis on room air reveals a pH of 7.35, $PaCO_2$ of 36 mmHg, and a PaO_2 of 60 mmHg.

EPIDEMIOLOGY AND GENERAL OVERVIEW

Acute respiratory failure remains a significant cause of morbidity and mortality. In the United States, the annual incidence of acute respiratory failure has been reported to be as high as 137 hospitalizations per 100,000 residents over the age of 5 years with an exponential increase for each additional decade up to the age of 85. Additionally, acute respiratory failure is very common in the intensive care unit (ICU) with as many as 56% of all ICU patients having this diagnosis at some point during their hospital course. Mortality rates also remain high with as many as 30–35% of patients succumbing in hospital. (1, 2) Multiple extrapulmonary factors, including age, the presence of infection or cardiovascular organ failure on ICU admission, the development of multiple organ failure while in the ICU, and a prior history of renal insufficiency, are associated with the development of acute respiratory failure and subsequent mortality.

DEFINITION OF ACUTE RESPIRATORY FAILURE

Acute respiratory failure results from the relatively sudden, hours to days, inability of the lungs to perform adequate alveolar gas exchange resulting in hypoxia. Additionally, this sudden decline in pulmonary function should represent a significant change from baseline level of function. The failure of normal alveolar gas exchange may result from dysfunction in any element of the respiratory system (central nervous system, musculoskeletal system, or the pulmonary parenchyma).

Alveolar gas exchange involves both oxygenation of blood and the removal of carbon dioxide. Consequently, respiratory failure can be classified as hypoxic (type I), dysfunctional oxygen exchange with adequate carbon dioxide exchange, or hypercapnic-hypoxic (type II), abnormal oxygen and carbon dioxide exchange (Figure 24.1). Hypoxic acute respiratory failure is frequently defined as an arterial partial pressure of oxygen (PaO_2) less than 55 mmHg and involves impaired oxygen transport. However, this criterion is relative and the circumstances surrounding each patient must be considered. For example, a patient with chronic lung disease may have a resting PaO_2 of 50 mmHg. Therefore, this patient would not be considered to be in acute respiratory failure. Hypercapnic-hypoxic acute respiratory failure is defined as an arterial partial pressure of

carbon dioxide ($PaCO_2$) of 50 mmHg or greater accompanied by an arterial pH of 7.3 or less. Although hypoventilation and subsequent CO_2 exchange is the primary impairment in this type of acute respiratory failure, significant hypoxia is nearly always present.(3)

SIGNS AND SYMPTOMS OF ACUTE RESPIRATORY FAILURE

Signs and symptoms of acute respiratory failure can range from the obvious to the very subtle and include shortness of breath, anxiety, altered mental status, cyanosis, the use of accessory muscles of respiration, diaphoresis, tachypnea, tachycardia, stridor, and hypoxia. Patients with pathology resulting in significant acute alterations in pulmonary physiology, such as a large pulmonary embolism, large pneumothorax/hemothorax, or advanced pneumonia, will manifest obvious signs and symptoms of respiratory failure. These patients will likely have pronounced tachypnea, tachycardia, diaphoresis, and hypoxia as well as complaint of severe shortness of breath. Frequently these patients prefer to sit upright and become progressively more agitated as their work of breathing progresses. However, patients with a more indolent course of acute respiratory failure may present with a much more subtle signs and symptoms.

Patients with suspected respiratory failure or insufficiency require rapid evaluation and intervention to avoid subsequent clinical deterioration and respiratory arrest. An assessment of the airway should be performed immediately in order to ensure patency and air movement. Further assessments of vital signs, oxygen saturation, other signs and symptoms of acute respiratory failure, as well as the need for endotracheal intubation and mechanical ventilation are warranted. Assessing the need for endotracheal intubation and mechanical ventilation involves evaluation of several factors including the presence of and the patient's ability to clear excessive pulmonary secretions, the patient's current oxygenation status, the presence of airway obstruction or pending airway obstruction, the patient's current mental status, and the patient's ability to maintain adequate minute ventilation. If endotracheal intubation and mechanical ventilation are not required, supplemental oxygen should be supplied as the etiology of the respiratory failure is sought. Chest radiograph and arterial blood gas analysis should be performed as they will aid in the search for a cause of the respiratory dysfunction. Other helpful diagnostic tools include bronchoscopy (with or without bronchio-alveolar lavage and culture), CT angiography of the chest, toxicology screens, head CT, and echocardiogram.(4)

ETIOLOGY/PATHOPHYSIOLOGY OF ACUTE RESPIRATORY FAILURE

Several mechanisms exist which can lead to a decreased PaO_2. These mechanisms include decreased fraction of inspired oxygen (FiO_2), ventilation–perfusion (V/Q) mismatch, hypoventilation,

Normal Alveolus

$PaO_2 > 55mmHg$
$PaCO_2 < 50mmHg$

Type I Respiratory Failure

1 **2**

Abnormal Alveolus

Thickened alveolar epithelium (1)
    ARDS
    Pneumonia
Fluid filled alveolus (2)
    Pulmonary Edema
    Inhalation Injury

⬇⬇ PaO_2

➡ $PaCO_2$

Type II Respiratory Failure

3

Normal Alveolus:

Hypoventilation without air trapping (3)
    CNS depression
    Chest wall abnormalities (rib fracutres)
Hypoventilation with air trapping (4)
    Obstructive (COPD)
    Restrictive (Asthma)
Increased dead space ventilation ($V_D/V_T > 0.50$) (5)

4

5

⬇⬇ PaO_2

⬆⬆ $PaCO_2$

Figure 24.1 Types of Respiratory Failure. Type I respiratory failure is secondary to impaired oxygen gas exchange in the affected alveoli. PaO_2 levels fall however $PaCO_2$ levels remain normal until late in the process. Type II respiratory failure is secondary to hypoventilation or impaired dead space ventilation (when $V_D/V_T > 0.50$) resulting in both decreased PaO_2 levels and increased $PaCO_2$ levels.

PaO_2 – arterial partial pressure of oxygen
CNS – central nervous system
$PaCO_2$ – arterial partial pressure of carbon dioxide
V_D – dead space ventilation
ARDS – acute respiratory distress syndrome
COPD – chronic obstructive pulmonary disease
V_T – total ventilation

shunting of deoxygenated blood into the systemic circulation, and impaired diffusion of oxygen across the alveolar epithelium (Table 24.1). *V/Q* mismatch and physiologic shunt nearly always coexist and are the main causes of hypoxia (Figure 24.2). *V/Q* mismatch and physiologic shunt can be distinguished by assessing the PaO_2 response to increases in FiO_2. In cases where *V/Q* mismatch is the main contributor to hypoxemia, significant corrections in PaO_2 levels and oxygen saturations can be made with minimal increases in FiO_2. However, when physiologic shunt is the main cause of hypoxemia, then small increases in FiO_2 have little to no effect on PaO_2 levels, and oxygen saturations and even large adjustments in FiO_2 result in only modest corrections of PaO_2 levels and oxygen saturations.(3, 5)

Once acute respiratory failure or insufficiency is identified and urgent assessment has been completed, a dedicated search for a clinical cause should be undertaken. The five main sources of hypoxemia should be considered and a list of potential clinical diagnoses (differential diagnoses) should be generated. Clinical assessments and diagnostic tools are used to narrow the list of potential diagnoses. Finally, once the diagnostic field has been sufficiently narrowed, a treatment plan tailored to the final diagnosis should be expeditiously put into place.

Our patient was rapidly evaluated by the ICU team. Chest radiograph demonstrated significant left-sided pulmonary consolidation, likely contusion. His symptoms improved with intravenous narcotics and epidural anesthesia. However, the following morning, the patient was again noted to be tachypneic, tachycardic, diaphoretic, short of breath, and using accessory muscles of respiration. Repeat room air arterial blood gas analysis reveals a pH of 7.32, $PaCO_2$ of 49 mmHg, and PaO_2 of 50 mmHg.

MONITORING PULMONARY FUNCTION

Patients at risk for acute respiratory failure require close monitoring for the development of signs and symptoms. Early detection of acute respiratory failure allows for prompt treatment which may include supplemental oxygen, continuous positive airway pressure (CPAP), noninvasive mechanical ventilation, or endotracheal intubation and mechanical ventilation.

Oxygenation

The presence of acute hypoxia and hypoxemia can be ascertained by measuring arterial oxygen saturation (SaO_2) and PaO_2. Assessment of SaO_2 can be done at the patient's bedside utilizing pulse oximetry. Assessment of PaO_2 requires arterial blood gas analysis. The degree of hypoxia and hypoxemia is quantified by these methods, and the diagnosis of acute respiratory failure is confirmed. The degree of hypoxia/hypoxemia can also be useful in ascertaining the severity of the acute respiratory failure.

Alveolar/Arterial Oxygen Gradient

Calculating the difference between the oxygen content within the alveolus (P_AO_2) and arterial blood (PaO_2) [$P(A-a)O_2$] will aid in determining the etiology of the acute respiratory failure. If the oxygen gradient is normal, then type II acute respiratory failure (hypercapnic-hypoxic) is present. In other words, when $P(A-a)O_2$ is normal then hypoventilation is responsible for the hypoxemia present. Etiologies include CNS depression, chest wall abnormalities, restrictive or obstructive lung disease, and increased dead space ventilation. When $P(A-a)O_2$ is increased, then hypoventilation, if present, does not explain all of the hypoxemia and some degree of pulmonary parenchymal dysfunction exists. Etiologies include ARDS, ALI, pneumonia, and pulmonary edema (Figure 24.1).

Physiologic Shunt

V/Q Mismatch

$V/Q = 0$

$V/Q = \infty$

Shunt Fraction = Q_S/Q_T

Figure 24 2 Comparison of Shunt and V/Q mismatch. Shunt results from blood entering the arterial system without first passing through any ventilated alveolar capillary system. Examples include normal physiologic shunt (bronchial venous return to pulmonary veins, coronary venous return to left ventricle) and abnormal physiologic shunt (right to left intracardiac shunt, patent ductus arteriosus). Main result of shunt is hypoxemia. V/Q mismatch results from ventilation and perfusion inequality occurring in various potions of the lung parenchyma. V/Q mismatch results in O_2 and CO_2 transport abnormalities.

Q_T – total pulmonary capillary blood flow
Q_S – shunted blood flow
Q_S/Q_T – shunt fraction
V – alveolar ventilation
Q – pulmonary capillary perfusion

Ventilation

In addition to oxygenation, ventilation should be closely monitored. The development of significant hypoventilation can be detected by following respiratory rate, serial spirometry (bedside incentive spirometry), and serial $PaCO_2$ measurements. The need for mechanical support secondary to fatigue and progressive hypoventilation should be determined prior to the development of severe hypoxia and respiratory collapse. Patients with progressive hypoventilation due to severe chest wall abnormalities, CNS depression, as well as restrictive or obstructive lung disease not responding to appropriate therapy will become tachypneic, hypercarbic, and, as fatigue sets in, these patients will demonstrate deterioration in serial spirometry. Early intervention with noninvasive ventilatory techniques or endotracheal intubation with mechanical ventilation is warranted. Delayed intervention resulting in crash intubation and mechanical ventilation should be avoided.

PaO2/FiO2 and Oxygen Index

The degree of pulmonary parenchymal dysfunction can be ascertained when the fraction of inspired oxygen (FiO_2) is known by calculating either the ratio of PaO_2 to FiO_2 (PaO_2/FiO_2) or the oxygen index (OI). When patients are intubated and mechanically ventilated for respiratory failure, these parameters are helpful in assessing response to treatment of the primary cause, particularly for type I (hypoxic) respiratory failure. Both parameters can be serially followed to assess the response to therapy. An increase in PaO_2/FiO_2 or a decrease in OI indicates improved pulmonary parenchymal function. A recent study suggests that SaO_2/FiO_2 correlates well with PaO_2/FiO_2 in patients with pulmonary dysfunction decreasing the need to assess pulmonary parenchymal function with serial arterial blood gas analyses.(6)

PaO_2/FiO_2 and OI differ in that OI accounts for the effect of mean airway pressure (MAP) on pulmonary parenchymal function, whereas PaO_2/FiO_2 does not. Increases in MAP can improve pulmonary parenchymal function by increasing functional residual capacity and recruiting previously collapsed alveoli for gas exchange over time. A patient on 50% FiO_2 and 20 cm H_2O positive end-expiratory pressure (PEEP) with a PaO_2 of 150 mmHg has a PaO_2/FiO_2 of 300, well above the threshold of 200 required for the diagnosis of respiratory distress syndrome. However, the OI would be more abnormal due to the increase in MAP caused by the use of higher PEEP.

> Once again our patient responded to aggressive respiratory therapy, supplemental oxygen administration, and pain control. However, within 4 h, he was found to be in respiratory distress with deteriorating spirometry measurements, progressive tachypnea, and an increasing hypercarbia and hypoxia on arterial blood gas analysis.

NONINVASIVE VENTILATORY SUPPORT

Certain patients with acute respiratory failure require more support than passive oxygen delivery and may benefit from noninvasive methods of ventilatory support. These noninvasive methods can support oxygenation alone or oxygenation and ventilation simultaneously. Additionally, use of these methods may obviate the need for endotracheal intubation and mechanical ventilation avoiding several severe complications, specifically ventilator-associated pneumonia.

CPAP applied by tight-fitting mask with adequate seal will maintain oxygenation by alveolar recruitment, resulting in increased functional residual capacity. CPAP has no effect on ventilation, and those patients with type II acute respiratory failure will not benefit from its use. Although intermittent positive pressure breathing aids in secretion clearance, due to its intermittent nature, no beneficial increases in functional residual capacity occur. Bilevel positive airway pressure (BiPAP) using pressure support and CPAP, however, will support both oxygenation and ventilation. This method has been found to decrease the need for mechanical ventilation in specific disease processes, specifically congestive heart failure (CHF) and COPD.(7) Similar to CPAP, BiPAP requires a tight-fitting mask and a patient with spontaneous respirations. These methods should be considered

Table 24.1 Mechanisms of Hypoxemia and Clinical Etiologies.

	Clinical Etiology
↓FiO2	High altitude
Ventilation-Perfusion (V/Q) Mismatch	Infiltrative Lung Disease Pneumonia Pulmonary Contusion Inflammatory Lung Disease ALI/ARDS Obstructive Lung Disease COPD Pulmonary Edema Pulmonary Embolism
Hypoventilation	Central Respiratory Depression Drugs Traumatic Brain Injury Peripheral Nerve Dysfunction Polyneuropathy of Critical Illness Guillain-Barre Syndrome Respiratory Muscle Dysfunction Critical Illness Myopathy Hypophosphatemia Myasthenia gravis
Physiologic Shunt	Intra-Cardiac Shunt Ventricular Septal defect Congenital Acquired Atrial Septal Defect Extra-Cardiac Shunt Intra-Pulmonary Shunt Pneumonia Atelectasis Pulmonary Contusion Pulmonary Edema ALI/ARDS
Impaired oxygen diffusion	These processes have a limited role in hypoxia at sea level. Sufficient time exists for diffusion during the transit of a red blood cell through the pulmonary capillary bed even in disease states

Table 24.2 Modes of Conventional Ventilation.

Mode	Characteristics	Benefits
Continuous Mandatory Ventilation (CMV)	Time-cycled Volume or Pressure limited Assumes most work of breathing from patient	Initial Vent Mode Minimizes work of breathing
Intermittent Mandatory Ventilation (IMV)	Patient does some work of breathing Any work of breathing done by patient depends upon number of breaths beyond preset rate If patient has no spontaneous breaths, this mode is equivalent to CMV	Allows some negative pressure breathing (spontaneous breaths) Transfers a portion of the work of breathing to patient
Pressure Support Ventilation (PSV)	Patient sets own respiratory rate, tidal volume, and flow rates Tidal volume dependent upon pulmonary and chest wall compliance Patient must have respiratory drive	Well tolerated Can transfer very small proportions of work of breathing by slowly decreasing PSV over time

CONVENTIONAL MECHANICAL VENTILATION

Once the need for endotracheal intubation and mechanical ventilation has been established, the methods of achieving adequate mechanical support must be determined (Table 24.2). Several modes of mechanical ventilation is to assume are available using a variety of commercially available ventilators. The primary decision involves determining the amount of work of breathing the ventilator is to assume. Modulation of the mode of mechanical ventilation will occur as the primary disease process resolves and the patient becomes ready to assume more work of breathing (wean from the ventilator).

Several other factors, in addition to mode of mechanical ventilation, must be considered when determining initial ventilator management. The FiO_2 is initially set at 100% and weaned to 30–40% as the patient's oxygenation status allows. Most conventional modes are time-cycled and an appropriate respiratory rate needs to be determined. This setting is based on the patient's ventilatory requirements ($PaCO_2$ level and arterial pH) as well as the inspiratory/expiratory ratio (*I:E*) which should be manipulated to allow for maximal exhalation time and minimal air trapping. Most patients will tolerate an *I:E* of 1:2 or greater. Patients with severe COPD, however, will need much longer *I:E* times (1:4–5). An additional parameter that effects *I:E* time is the inspiratory flow rate. The higher the inspiratory flow rate the longer the exhalation cycle. However, higher inspiratory flow rates contribute to higher peak airway pressures. Sensitivity settings determine the amount of inspiratory effort the patient must exert, in order for the ventilator to assist a spontaneous breath. These are usually set at -2 to -1 cm H_2O. Finally, PEEP is usually delivered at 5 cm H_2O for most patients. However, patients requiring higher MAP to support oxygenation may require higher levels of PEEP (Table 24.3).

Assist Control and Continuous Mandatory Ventilation

Initially, after endotracheal intubation, the ventilator should assume as much of the work of breathing as possible. Assist control (A/C) or continuous mandatory ventilation (CMV) modes

short-term therapies, allowing for the identification and treatment of underlying issues. Close monitoring of all patients supported with these modalities is warranted to identify signs of deterioration requiring endotracheal intubation and mechanical ventilation.(4)

Caution should be used when considering use of noninvasive methods of ventilator support in those patients with postextubation respiratory failure. In this group of patients, use of these modalities to avoid reintubation and reinitiation of mechanical ventilation has been reported to be associated with increased mortality.(8)

After having success with BiPAP for 18 h, our patient is now confused and hypoxic. He continues to pull off the tight-fitting face mask and rapidly desaturates to 80% SaO_2 by pulse oximetry. His respiratory rate is now 38 breaths per minute with nasal flaring and intercostal muscle retraction. He is disoriented. The ICU nursing staff calls you to the bedside to evaluate the need for endotracheal intubation and mechanical ventilation in this patient.

Table 24.3 Common Parameter Settings for Conventional Ventilators.

Mode	A/C or CMV/IMV/PSV/CPAP
Volume-limited (volume control)	Constant (set) tidal volume (V_T) delivered with each mandatory and assisted breath
Pressure-limited (pressure control)	Tidal volume (V_T) <u>not</u> constant Lung insufflated until a set peak pressure limit is reached Tidal volume dependent upon lung and chest wall compliance
Respiratory Rate	Determined by ventilator needs Arterial pH $PaCO_2$
Sensitivity	Usually set at −2 to −1 cm H_2O
I:E Ratio	Usually set at 1:2 or greater to minimize air trapping Will also depend on rate (higher rates result in lower I:E ratios) I:E ratio can be inverted (2:1) to augment oxygenation
Inspiratory Flow Rate	Usually set at 60–70 L/min May adjust to patient comfort or to attain certain I:E ratio Increasing flow rate decreases inspiratory time and lengthens I:E ratio Increasing flow rates increases peak airway pressure
PEEP	Usually initially set at 5 cm H_2O Can increase to augment oxygenation

are best suited for this purpose, although the muscles of respiration, specifically the diaphragm, cannot be completely unloaded. A/C and CMV deliver a preset level of minute ventilation (continuous ventilation) in patients without spontaneous respirations or augment any patient-initiated breath (assisted breath) and deliver additional breaths (controlled breath), in order to assure a preset level of minute ventilation when spontaneous respirations are present.

A/C or CMV can be either volume limited (volume control) or pressure limited (pressure control). Volume control and pressure control differ in the manner in which the positive pressure inhalation cycle is delivered. In volume control ventilation, inspiration is continued until a preset tidal volume is fully delivered. Peak airway pressure with each breath is therefore determined by pulmonary and chest wall compliance and is not constant. For example, if a patient on volume control ventilation develops a pneumothorax, peak airway pressures will rise as the ventilator delivers a constant (preset) tidal volume with each breath. In pressure-control ventilation, inspiration is continued until a preset airway pressure limit is detected. Tidal volume with each breath is therefore determined by pulmonary and chest wall compliance and is not constant. For example, if a patient on pressure-control ventilation develops a pneumothorax, tidal volume will decrease as the pressure limited is reached earlier and earlier within the inspiratory cycle as the pneumothorax increases in size.

Synchronized Intermittent Mandatory Ventilation

When a patient is ready to assume some work of breathing, intermittent mandatory ventilation (IMV) is an appropriate mode.

A patient may be ready to assume work of breathing shortly after endotracheal intubation or a much longer time period may need to pass before the patient is able to tolerate negative pressure (spontaneous) breathing. Similar to CMV, IMV delivers a preset level of minute ventilation. However in contrast to CMV, any wok of breathing and minute ventilation required beyond this defined preset value will be completely generated by the patient. All breaths occurring beyond the set rate when in an IMV mode are not assisted by the ventilator. Patients not breathing beyond the preset rate (no spontaneous breaths) in an IMV mode are essentially receiving CMV. As with CMV, IMV can be either volume limited (volume control) or pressure limited (pressure control). Lastly during IMV, the ventilator synchronizes (SIMV) all mandatory breaths with the patient's spontaneous efforts, in order to prevent breath stacking and alveolar distension.

Pressure Support Ventilation

Another option for a patient ready to assume some work of breathing is pressure support ventilation (PSV). PSV is not time-cycled and requires that the patient have an adequate respiratory drive. There is no mandatory minute ventilation delivered. However, PSV is very well tolerated since the patient determines their own respiratory rate, tidal volume, and inspiratory flow rate. PSV supplies to the patient a preset level of pressure during the inspiratory limb of the respiratory cycle generating the tidal volume. Tidal volume is therefore determined by the pulmonary and chest wall compliance. A patient with normal compliance will require a lower pressure support setting to generate adequate tidal volumes. A patient with abnormal compliance will require a higher pressure support setting to generate adequate tidal volumes. Usually initial PSV settings are used to achieve a comfortable respiratory rate (<25 breaths per minute). If respiratory rate increases, then PSV is adjusted to increase tidal volume with a resultant decrease in respiratory rate. Since PSV is not time-cycled, changes in flow rates detected by the ventilator during inspiration determine the inhalation and exhalation cycles. When flow rates during inspiration decrease by 75%, the pressure applied to the airway is halted and passive expiration begins. The next inspiratory cycle is triggered when the patient initiates another negative pressure breath. Lastly, PSV can be combined with SIMV to provide some ventilatory support during spontaneous breaths (SIMV/PSV). In other words, the patient breaths occurring beyond the preset minute ventilation in SIMV are unsupported. When PSV is used in combination with SIMV, these spontaneous breaths receive the preset amount of pressure support.(9)

ADJUNCTS TO CONVENTIONAL MECHANICAL VENTILATION

Several adjuncts to conventional mechanical ventilation have been described to aid in augmenting oxygenation and carbon dioxide removal. These adjuncts can be used individually or together as the patient's respiratory status demands.

Positive End-Expiratory Pressure

PEEP augments oxygenation by increasing MAP and recruiting collapsed alveoli for gas exchange. The effects of PEEP are time dependent, and its benefits are usually not noted immediately.

When a patient requires higher PEEP to attain adequate oxygenation, any maneuver that disrupts the ventilator circuit, such as endotracheal suctioning, should be avoided. Ventilator circuit disconnection while higher PEEP is being utilized can result in rapid alveolar derecruitment and hypoxia.

Lung-Protective Strategies

Barotrauma from alveolar overdistention at end inspiration and repetitive alveolar collapse at end expiration have been postulated to contribute to lung injury.(10) Several studies have reported benefits with the use of lung-protective strategies defined as low tidal volumes (6 ml/kg), to protect against overdistention, and high PEEP levels, to protect against alveolar collapse. Other guidelines for a protective lung strategy include plateau pressure $\leq$ 30 cm H_2O, PaO_2 55–80 mmHg or SaO_2 88–95%, FiO_2/PEEP ratio of $\leq$ 5:1, and arterial pH 7.25–7.45 with a maximal respiratory rate of 35 breaths per minute.(11–13)

Permissive hypercapnia

Deliberate hypoventilation can be utilized to limit alveolar overdistention and barotrauma within compliant lung segments in patients with acute respiratory distress syndrome. Tidal volume is gradually reduced to allow $PaCO_2$ to rise to 80–110 mmHg. This rise in $PaCO_2$ is accompanied by a concomitant respiratory acidosis (arterial pH as low as 7.15). Arterial oxygen saturations are kept at or above 90%.(14)

Prone Positioning

Placing patients intermittently into a full-prone position has been shown to improve measures of oxygenation in severely hypoxic patients with acute respiratory distress syndrome without effecting hemodynamics. Additionally, no effects on most outcome measures, specifically mortality, have been noted. The most frequent adverse effects of prone positioning were the need for increased sedation and increased incidence of facial edema. Prone positioning did not increase the rate of pressure ulcers or the incidence of complications involving endotracheal tube, intravascular catheter, or thoracostomy tube dislodgment.(15) The mechanisms resulting in improved oxygenation with prone positioning have been postulated to include improved mobilization of secretions, a change in chest wall dynamics resulting in better ventilation of the posterior (dorsal) segments, and improved ventilation–perfusion relationships.(16, 17)

Recruitment Maneuvers

Alveolar recruitment enhances functional residual capacity and opens collapsed areas of lung allowing increased alveolar surface area for gas exchange. The proportion of potentially recruitable lung in patients with acute respiratory distress syndrome has been reported to be up to 13±11%. Alveolar recruitment maneuvers include sustained high-pressure maneuvers (40–60 cm H_2O airway pressure for 30 s) or periodic high-pressure maneuvers (40–60 cm H_2O airway pressure for several seconds repeated several times over 1 minute). These maneuvers appear to be beneficial in patients with acute lung injury; however, no single clinical trial has described significant improvement in survival.(14, 18)

SPECIALTY MODES OF MECHANICAL VENTILATION

Several specialty modes of ventilation have been developed to potentially rescue patients with severe acute respiratory distress syndrome and profound hypoxia. The methods can augment oxygenation; however, the effects on long-term outcomes remain unresolved.

High-Frequency Oscillatory Ventilation

High-frequency oscillatory ventilation (HFOV) utilizes a piston-driven pump system, which moves a small reciprocating diaphragm creating oscillations in a column of air delivering small tidal volumes at high frequencies to the alveolar air spaces. Respiratory rates range from 60 to 300 breaths per minute (1–5 Hz) in adults. Oxygenation is controlled by maintaining a constant MAP. Lung protection is achieved by the lack of large pressure oscillations in HFOV compared to the pressure changes occurring with conventional ventilation. Since HFOV maintains airway pressure at a very nearly static state (very small pressure changes around a preset MAP), the alveolar capillary membranes theoretically experience less barotrauma. Additionally, with the small pressure fluctuations in HFOV much higher MAPs can be maintained, further augmenting oxygenation. Ventilation is addressed by manipulating frequency (lower frequency results in a higher tidal volume and a decrease in $PaCO_2$) as well as adjusting power (amount of movement of piston) and inspiratory time. Some authors have described using a small endotracheal tube cuff leak to augment CO_2 elimination. Similar to other methods, use of HFOV has been found to increase measures of oxygenation but no consistent effect on survival has been reported.(19, 20)

High-Frequency Percussive Ventilation

High-frequency percussive ventilation (HFPV), also called volumetric diffusive respiration (VDR), is a time-cycled, pressure-limited mode of ventilation with the addition of a sliding Venturi mechanism between the inspiratory and expiratory flow circuits. This Venturi mechanism, or phasitron, is driven by a high-flow gas supply at a frequency of 200–900 cycles/minute (3–15 Hz). The addition of the phasitron to the time-cycled pressure-limited ventilation cycle results in a hybrid form of ventilation. There is delivery of a more conventional preset tidal volume at a preset conventional respiratory rate as well as a superimposed delivery of a much smaller subtidal volume at much higher respiratory rate. This allows for properties of both conventional pressure-control ventilation and HFOV. A higher airway pressure can be maintained in order to augment oxygenation. Again, studies have shown an improvement in measures of oxygenation but no real change in overall outcome.(21)

Airway Pressure Release Ventilation

Although *airway pressure release ventilation* (APRV) is mentioned in this section on specialty modes of ventilation used to rescue patients with severe hypoxia and acute respiratory distress syndrome, this mode is also frequently used routinely as a primary mode of mechanical ventilation. APRV is a time-cycled, pressure-limited mode of ventilation, which allows a patient unrestricted spontaneous breathing during the application of

CPAP with the addition of periodic release of airway pressure to facilitate ventilation. The ventilator maintains a high-pressure setting (P_{High}) for much (80–95%) of the respiratory cycle (T_{High}) with periodic release to a lower pressure setting (P_{Low}) for a much shorter time period (T_{Low}). As mentioned, spontaneous breathing can occur at any time throughout the APRV cycle. This mode is beneficial in that it is very well tolerated by patients and requires much less sedation than pressure-control ventilation.(14, 22)

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25 Ventilator-associated pneumonia

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An 80-year-old female with a history of chronic obstructive pulmonary disease and diabetes mellitus undergoes an emergent Hartmann procedure for perforated diverticulitis. She is brought to the surgical intensive care unit (ICU) ventilated mechanically after receiving several liters of crystalloid and two units of blood intraoperatively. She has normal hemodynamics and is alert on ICU admission with adequate urine output. Overnight, she becomes hypotensive, requiring large-volume fluid resuscitation and intermittent vasopressor support. She is kept intubated. On postoperative days 1 and 2, vasopressor support is withdrawn gradually, and diuresis is begun in anticipation of extubation. Enteral feedings are begun via the nasogastric route.

On postoperative day 4, the patient develops a temperature of 39.9°C as well as tachycardia and intermittent hypotension, both of which respond to fluid administration. Her white blood cell count is elevated to 17.5 x 10^9 cells/L, and a new opacification in the right lower lobe is identified on chest radiography (CXR). The patient undergoes bronchoscopy; thick, purulent secretions are visualized in the airways of the right lower lobe. Lower respiratory tract samples are obtained via bronchoscopic bronchoalveolar lavage (BAL) and sent for analysis using quantitative microbiology. Blood cultures are drawn and broad-spectrum antibiotics—vancomycin (15 mg/kg q12h) and piperacillin-tazobactam (4.5 g q6h) —are initiated. Gram stain reveals gram-positive cocci in clusters. Forty-eight hours later, the BAL culture yields > 10^5 CFU/mL of methicillin-resistant *Staphylococcus aureus* (MRSA), sensitive to vancomycin. A vancomycin trough concentration is obtained before the fourth dose and is within range (15–20 mcg/mL). Piperacillin-tazobactam is discontinued, and an 8-day course of vancomycin is completed. The patient's temperature and white blood cell count normalize and the CXR improves within three days. The patient is extubated on postoperative day 7, continued on parenteral antibiotics until day 12, and discharged home on postoperative day 14.

EPIDEMIOLOGY

Ventilator-associated pneumonia (VAP) comprises nearly one-third of all ICU infections.(1–4) The incidence of VAP depends upon the diagnostic criteria utilized, and thus varies markedly in published reports. Clinical criteria alone overestimate the incidence of VAP as compared with either microbiologic or histologic data.(5, 6) Safdar et al. performed a systematic review of 89 studies in which the incidence of VAP among mechanically ventilated patients was reported.(7) Despite substantial heterogeneity of diagnostic criteria, the authors reported a pooled incidence of VAP of 22.8% [95% confidence interval (CI) [18.8–26.9%]. The National Nosocomial Infection Surveillance (NNIS) system reported recently that VAP occurred at a rate of 7.5 cases per 1,000 ventilator days in medical ICUs and 13.6 per 1,000 ventilator days in surgical ICUs.(8) The incidence of VAP varies with the duration of mechanical ventilation, increasing at a rate of 3% per day during the first 5 days, 2% per day during days 5–10, and 1% per day after that.(9) Risk factors for VAP are summarized in Table 25.1.

> The case patient had several risk factors for developing VAP, including advanced age, preexisting pulmonary disease, intraoperative blood transfusion, and prolonged endotracheal intubation.

Perhaps most important is airway intubation itself. The risk of hospital-associated pneumonia (pneumonia that occurs > 48 h from the time of admission) increases 6–20-fold in mechanically ventilated patients (3, 10, 11); patients with respiratory failure managed with noninvasive, positive-pressure ventilation (NIPPV) have a lower incidence of pneumonia.(12–14) VAP is especially common in patients with the acute respiratory distress syndrome (ARDS), owing to prolonged mechanical ventilation and devastated local airway host defenses.(15–17)

Whether VAP is an independent risk factor for mortality is controversial.(18) Most recent series have reported a crude mortality rate in patients with VAP of 9–27% (2, 19–22), although rates can exceed 75% in high-risk patients infected with multidrug-resistant organisms (MDRO).(15, 23) Assignment of attributable mortality in patients with VAP has been problematic because, compared to non-VAP patients, patients who develop VAP are systemically more ill upon intubation.

Several authors have addressed this issue through a matched cohort study design. Heyland et al. matched 177 patients who developed VAP to controls by age, admission diagnosis, location prior to ICU, and admission Acute Physiology and Chronic Health Evaluation (APACHE) II score.(24) Patients who developed VAP had a significantly longer ICU length of stay (LOS), but no increase in mortality (23.7% vs. 17.7%, $p = 0.19$). Furthermore, attributable mortality was highest for patients infected with high-risk organisms, defined as MRSA, *Pseudomonas*, *Acinetobacter*, and *Stenotrophomonas*. However, appropriate initial empiric therapy may mitigate adverse outcomes.(25) Hugonnet et al. matched patients with and without VAP by age, severity of illness, and duration of mechanical ventilation before the development of VAP.(26) Compared to non-VAP patients, patients with VAP suffered an increased ICU LOS, duration of mechanical ventilation, and ICU costs, but not mortality (32.0% vs. 24.7%, $p = 0.26$). However, when these and other matched-cohort studies were pooled by meta-analysis, patients with VAP were more than twice as likely to die compared to those without VAP (odds ratio [OR] 2.03, 95% CI 1.16–3.56, $p = 0.03$) and incurred both a longer ICU LOS and a mean increased ICU cost of $10,019.(7)

Table 25.1 Risk Factors for VAP.

Age ≥ 60 years
Acute respiratory distress syndrome
Chronic obstructive pulmonary disease or other underlying pulmonary disease
Coma or impaired consciousness
Serum albumin < 2.2 g/dL
Burns, trauma
Blood transfusion
Organ failure
Supine position
Large-volume gastric aspiration
Sinusitis
Immunosuppression

PATHOGENESIS

Both impaired host immunity and displacement of normal oropharyngeal flora by pathogens predispose the critically ill, mechanically ventilated patient to VAP. Normal nonspecific host defenses, such as the epiglottis, vocal cords, cough reflex, and ciliated epithelium and mucus of the upper airways are either bypassed or rendered ineffective during intubation. Bacteria gain access to the lower respiratory tract via aspiration through the endotracheal tube (where they may establish colonies impervious to the effects of antibiotics in the glycocalyx biofilm that coats the lumen of artificial airway devices), migration around it (particularly if cuff inflation pressure is not maintained), or, in rare instances, hematogenous spread from blood stream infections. Displacement of normal flora by pathogens is also necessary for the development of VAP.(27–29) Both the facial sinuses and stomach may serve as potential pathogen reservoirs, but measures to minimize passage of pathogens from these sources into the lower airways have provided mixed results.

Currently, the most common pathogens isolated from patients with VAP are MRSA (15%), *Pseudomonas* (14%), *Enterobacter* (3%), *Escherichia coli* (3%), and *Acinetobacter* (2%).(5, 23) Due to indiscriminant use of broad-spectrum antibiotics, MDRO pathogens are implicated increasingly in VAP.(30–33) Infection with MRSA is particularly common in patients with diabetes mellitus and after traumatic brain injury.(33–35) *Pseudomonas aeruginosa*, the most common gram-negative pathogen in VAP, is increasingly common with an MDRO phenotype, especially to both fluoroquinolones (31, 36) and third-generation cephalosporins.(37)

Anaerobic bacteria are isolated infrequently from patients with VAP, although this finding may represent an inability to culture these organisms effectively from an oxygen-enriched environment—the mechanically ventilated airway.(38) Although isolation of fungi such as *Candida* spp. and *Aspergillus fumigatus* from endotracheal aspirates (EAs) is common, it nearly always represents colonization of the immunocompetent host. (39–42) However, when fungi are isolated from two or more normally sterile sites (e.g., urine and lower respiratory tract) in an immunocompromised patient, systemic antifungal therapy should be considered.

PREVENTION

Prevention of VAP requires a thorough understanding of modifiable risk factors. Strict infection control, including hand hygiene with alcohol-based hand disinfectants, gowning, and gloving, minimizes person-to-person transmission of pathogens and is paramount to deterring all ICU infections.(43, 44) Prevention of VAP begins with minimization of endotracheal intubation and the duration of mechanical ventilation. NIPPV should always be considered in lieu of intubation, as patients with respiratory failure managed with NIPPV have a lower incidence of VAP.(12–14, 45) Evidence-based strategies to decrease the duration of mechanical ventilation include daily interruption of sedation (46), standardized weaning protocols, and adequate ICU staffing.(47)

If endotracheal intubation is mandated, the orotracheal compared to the nasotracheal route may decrease the risk of developing VAP. Holzapfel et al. found that the incidence of VAP in patients who were randomized to orotracheal intubation was only one-half that of patients intubated nasotracheally (6% vs. 11%). (48) In light of these data, and the association between nasotracheal intubation and the development of nosocomial sinusitis (49), orotracheal intubation is preferred.

Once intubation has occurred, the majority of preventive measures against VAP decrease the risk of aspiration. Both maintenance of endotracheal cuff pressure > 20 cm H_2O (50) and continuous aspiration of subglottic secretions achieved through the use of an endotracheal tube equipped with an additional lumen above the balloon reduce the incidence of VAP.(51–56) Furthermore, strong evidence exists that semirecumbent positioning (30°–45° head-up) is protective, as compared to supine positioning, especially during enteral feeding.(57–59)

Compared to post-pyloric feeding, intragastric feeding results in more episodes of both gastroesophageal reflux and aspiration.(57) However, recent randomized, controlled trials (RCTs) comparing rates of VAP have produced variable results.(58, 59) Heyland et al. performed a meta-analysis of 11 RCTs and reported a RR of 0.77 (95% CI [0.60–1.00, $p = 0.05$) for VAP with post-pyloric as compared to gastric feedings.(60) Based on these data, most expert recommendations do not differentiate between gastric and post-pyloric feeding.(60–65) Pro-motility agents such as erythromycin may facilitate safe intragastric feeding, should this route be used.(66)

The timing of onset of enteral feedings may influence the risk of developing VAP. Initiation of enteral feeds on day 1 compared to day 5 resulted in significantly more episodes of VAP (49.3% vs. 30.7%, $p = 0.02$) and a longer ICU LOS in a prospective trial of 150 patients.(67) More recently, Shorr et al. reported that enteral nutrition begun ≤ 48 h after the initiation of mechanical ventilation was independently associated with the development of VAP (OR 2.65, 95% CI 1.93–3.63, $p < 0.0001$).(68)

Pharmacologic strategies intended to minimize the risk of aspiration of pathogenic bacteria include selective decontamination of the digestive tract (SDD) with topical or systemic antibiotics or antiseptics, and minimization of stress ulcer prophylaxis. Myriad clinical trials have addressed SDD, most of which have reported a significant decrease in the incidence of VAP.(69–74) However, the evidence in favor of SDD has been limited by questionable study

methodology (75), use of narrow patient subsets from ICUs in which MDRO pathogens were rare, and an increased number of infections caused by MDRO observed in the SSD groups.(76–78) For these reasons, use of SDD is currently not recommended for the routine prevention of VAP.

Alternatively, oropharyngeal decontamination can be accomplished with a topical antiseptic, such as chlorhexidine. Recent RCTs have provided evidence for (79) and against (80) the efficacy of chlorhexidine in the prevention of VAP. A recent meta-analysis showed a significant reduction in the rate of VAP among patients treated with oral chlorhexidine (81), which is beginning to be incorporated into oral care regimens for ventilated patients. Further research is warranted before final recommendations can be made.

Stress ulcer prophylaxis is a known risk factor for the development of VAP (29, 82); its use should be reserved for patients at high risk for gastrointestinal mucosal hemorrhage (e.g., prolonged mechanical ventilation, intracranial hemorrhage, coagulopathy, glucocorticoid therapy). RCTs comparing histamine type-2 antagonists, sucralfate, and antacids have yielded conflicting results (83–88); no agent is preferred for prophylaxis based solely on efficacy for prevention of VAP.

Ample data document the relationship between blood transfusion and infection risk in surgical (89–91), trauma (92), and critically ill patients.(93) Shorr et al. found red blood cell transfusion to be independently associated with the development of VAP (OR 1.89, 95% CI 1.33–2.68, $p = 0.0004$).(68) Early et al. documented a decreased incidence of VAP in a surgical ICU following implementation of an anemia management protocol.(94) After implementation of the protocol, fewer blood transfusions were administered despite equivalent outcomes, and the incidence of VAP decreased from 8.1% to 0.8% ($p = 0.002$).

Several antibiotic administration strategies, including "deescalation" and antibiotic rotation or "cycling," have been suggested to prevent VAP caused by MDR pathogens. Deescalation refers to the process of tailoring empiric broad-spectrum antimicrobial coverage to specific pathogens once microbiologic data from lower respiratory tract samples become available. Discontinuation of unnecessary antibiotics at this point curtails not only the emergence of MDRO but also the risk of drug toxicity.

> The case patient's antibiotics were deescalated when culture and sensitivity data allowed specific targeting of the bacteria causing the pneumonia.

Antibiotic cycling offers the potential for antibiotic classes to be used on a scheduled basis to preserve overall activity against predominant pathogens.(95, 96) Several prospective trials have documented a decreased incidence of VAP (97, 98), improved initial adequacy of therapy (25), and decreased mortality (99) following the implementation of scheduled antibiotic rotation. However, these studies have been limited by the use of historical controls, and thus possible confounding by other changes in care. Furthermore, recent data have challenged the efficacy of antibiotic cycling.(100) Pending further research, cycling of antibiotics may be considered if multiple classes of antibiotics are cycled

frequently in conjunction with other strategies to prevent the emergence of MDRO.(101) Finally, staff education programs concerning modifiable risk factors may be cost-effective in preventing VAP. Zazk et al. demonstrated that an education program administered to respiratory care practitioners and intensive care nurses that highlighted correct practices for the prevention of VAP resulted in a significantly decreased incidence of VAP and increased cost savings.(102)

DIAGNOSIS

The goals in diagnosing VAP are to determine if the patient has pneumonia and to determine the etiologic pathogen. Poor specificity is particularly problematic in the diagnosis of VAP because it not only exposes individual patients to unnecessary risk from overtreatment with antibiotics but also increases selection pressure and thus the emergence of MDRO bacteria within the ICU.(31, 103) Conversely, inadequate initial therapy in patients with VAP (poor sensitivity) has been associated consistently with increased mortality that cannot be reduced by subsequent changes in antibiotics.(104)

> Concern for VAP was raised in the case patient due to fever, leukocytosis, and a new infiltrate on chest radiography.

The diagnosis of VAP should be considered in the presence of one or more of the following: fever, leukocytosis or leukopenia, purulent sputum, hypoxemia, or a new or evolving infiltrate viewed on CXR. However, several noninfectious respiratory disease processes may mimic these signs, such as congestive heart failure, atelectasis, pulmonary thromboembolism, pulmonary hemorrhage, and ARDS, making clinical criteria alone nonspecific. Fabregas et al. found the presence of a new infiltrate on CXR, along with two of the three aforementioned clinical criteria, to be 69% sensitive and 75% specific for the diagnosis of VAP when compared to postmortem histology.(105) Several subsequent reports have confirmed the low specificity of clinical acumen in the diagnosis of VAP (106–108), and clinically diagnosed VAP is confirmed microbiologically in fewer than 50% of cases.(6, 109, 110)

Pugin et al. standardized clinical, radiographic, and microbiologic criteria into the clinical pulmonary infection score (CPIS).(111) Temperature, leukocyte count, chest radiographic infiltrates, the appearance and volume of tracheal secretions, $P_aO_2:F_IO_2$, and culture and gram stain of tracheal aspirate (0–2 points each) yield a maximum CPIS score of 12 points; a score of > 6 points indicates a high probability of VAP. Despite favorable test performance of the CPIS in its initial description, and its subsequent modification to include radiological progression of pulmonary infiltrates (112), the specificity of CPIS is no better than clinical acumen alone when compared to lower respiratory tract cultures obtained via bronchoscopic BAL or protected specimen brush (PSB).(113–115) The NNIS system diagnostic criteria for nosocomial pneumonia (116), which include similar combinations of clinical and radiographic parameters, performs equivalently

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to the CPIS when compared to quantitative lower respiratory tract cultures.(117) Incorporation of results from gram-stained lower respiratory tract samples into the CPIS improves specificity only marginally.(113) However, the negative predictive value of a gram stain showing no organisms in a clinically stable patient approaches 100%.(118)

Because of the low specificity of clinical signs, radiographic criteria, and microscopic examination of lower respiratory tract samples, culture of lower respiratory tract samples prior to any manipulation of antibiotics is mandatory for workup of suspected VAP in order to minimize false-negative results.

> Once VAP was suspected, lower respiratory tract samples were obtained by bronchoscopic BAL from the case patient prior to the initiation of antibiotic therapy.

Two fundamental issues regarding lower respiratory tract samples are debated: the method of specimen collection (invasive vs. noninvasive) and the method of specimen analysis (semiquantitative vs. quantitative). Noninvasive techniques include sampling of the lower respiratory tract via EAs, blinded plugged telescoping catheter (PTC), blinded PSB, and mini-BAL. EAs are less specific due to both an increased likelihood of contamination by oropharyngeal flora (indicated by the presence of squamous epithelial cells on gram stain) and an increased likelihood that the presence of organisms indicates colonization rather than infection.

Invasive techniques (BAL or PSB) collect lower respiratory tract samples using fiberoptic bronchoscopy. The main theoretical advantage of bronchoscopy is direct visualization of the airways. However, invasive techniques are both more expensive and resource intensive than their noninvasive counterparts and may not be available readily. Furthermore, although bronchoscopy is generally well tolerated, a significant reduction in arterial oxygen saturation has been observed for up to 24 h following the procedure, possibly related to alveolar flooding caused by residual lavage fluid. However, this transient desaturation is of unclear importance, not having been correlated with poorer outcomes.(119)

Irrespective of collection method, respiratory tract cultures may be analyzed using either semiquantitative or quantitative microbiology. The crucial issue is distinction of colonization from infection.(120) Whereas semiquantitative microbiology reports growth in terms of ordinal categories (e.g., light, moderate, or heavy), quantitative microbiology reports growth in number of colony forming units per milliliter of aliquot. In the latter case, a threshold value is selected to distinguish colonization from infection. Commonly used thresholds are 10^3 CFU/mL for PSB, 10^4 CFU/mL for BAL, and 10^5 CFU/mL for EA. It is generally recommended that any threshold be lowered at least one order of magnitude if antibiotics have been changed recently or started prior to sample acquisition.(121)

EAs possess inferior specificity when compared to both blinded PTC (121) and bronchoscopic BAL or PSB.(123–126) Two systematic reviews, one of bronchoscopic BAL (119) and one of blinded invasive techniques (127), reported similar test characteristics for the two techniques. However, methodologic

variability is rampant. Of 23 studies (70%), in the former review, 16 studies used histology as a reference standard, compared to only 4 of 15 studies (27%) analyzed in the latter review. Furthermore, the remainder of studies analyzed in the review of blinded invasive techniques used either bronchoscopic BAL or PSB as the reference category. Both reviews reported substantial interstudy variability in sampling technique as well as threshold values. A recent study reported that compared to a reference standard of bronchoscopic BAL (threshold 10^4 CFU/mL), blinded PTC was 77% sensitive and 94% specific.(126) Thus, despite these limitations, it is likely that bronchoscopic techniques are more specific than blinded techniques and that both techniques are superior to EAs.

Evidence-based recommendations for the diagnosis of VAP have been difficult to formulate because many RCTs have compared various permutations of collection and analytical methodology, threshold values, and reference categories. The largest RCT of this type compared an invasive, quantitative approach with a noninvasive, semiquantitative approach.(6) A total of 413 patients suspected of VAP were randomized to evaluation with either bronchoscopic BAL or PSB with quantitative cultures, or "clinical" management consisting of semiquantitative analysis of EAs. Antibiotic therapy was discontinued in clinically stable patients with negative culture results, regardless of study arm. Compared to the clinical strategy, patients in the invasive group demonstrated decreased 14-day mortality (16% vs. 25%, $p = 0.02$), less antibiotic use (11.9 vs. 7.7 antibiotic-free days), decreased sepsis-related organ failure, and decreased 28-day mortality after adjustment for severity of illness. The clinical strategy also resulted in more and broad-spectrum antibiotic therapy compared to the invasive strategy and increased emergence of fungi. It is unclear whether these improved outcomes resulted from the use of an invasive vs. a noninvasive sputum collection strategy or a quantitative vs. a semiquantitative analysis strategy.

Two RCTs have compared outcomes of patients with suspected VAP managed with an invasive vs. a noninvasive approach when both samples were cultured quantitatively. Sanchez-Nieto et al. randomized 51 patients with suspected VAP to EA vs. bronchoscopic BAL or PSB.(126) Initial antibiotic therapy was modified in a significantly higher percentage of invasive patients compared to noninvasive patients (42% vs. 16%, $p < 0.05$), but there was no difference in severity-adjusted mortality, ICU LOS, or duration of mechanical ventilation. Ruiz et al. randomized 76 patients with suspected VAP to EA vs. bronchoscopic BAL or PSB and found no difference in incidence of antibiotic modification, duration of mechanical ventilation, ICU length of stay, crude mortality, or adjusted mortality.(128) In both studies, antibiotics were continued in all patients with negative cultures.

Shorr et al. performed a meta-analysis of the aforementioned trials comparing EA (either quantitative or semiquantitative) to bronchoscopic quantitative cultures.(129) Although the pooled OR suggested a survival advantage to the invasive approach (OR = 0.62), the result was not significant. However, patients in the invasive group were more likely to undergo changes in antimicrobial regimen.

In conclusion, samples obtained via bronchoscopic BAL or PSB and then analyzed quantitatively have the highest specificity

in diagnosing VAP. Data reporting outcomes in patients managed with an invasive vs. a "clinical" strategy are conflicting, although the largest such trial showed a significant survival advantage for patients managed with the invasive/quantitative approach. Several trials demonstrate that patients so managed are also more likely to undergo antibiotic changes. Trials rebutting the use of the invasive/quantitative strategy are limited because patients with negative cultures continued to receive antibiotics, which negates the putative benefit (the ability to discontinue antimicrobial therapy). This last point is of considerable importance because the value of invasive, quantitative specimens lies not with their impact upon the decision to initiate therapy (these cultures will not become available for 48–72 h), but rather with their effect upon either alteration or discontinuation of antibiotic therapy based on final results.

> Lower respiratory tract samples obtained from the case patient were obtained using bronchoscopic BAL and were analyzed quantitatively, yielding > 10^5 CFU/mL of MRSA .

TREATMENT

Neither the decision to initiate antimicrobial therapy nor the choice of specific agents involves interpretation of lower respiratory tract cultures, which will not become available for 48–72 h. Rather, the decision to initiate therapy is based on clinical suspicion and microscopic examination of gram-stained lower respiratory samples. Furthermore, choice of agent is based on both individual patient risk factors for infection with MDR organisms and data from institutional (ideally unit-specific) antibiograms. The majority of data indicate that antimicrobial therapy may be withheld safely if (1) a gram-stained lower respiratory tract sample reveals no organisms and (2) the patient has no signs of severe sepsis.(131–134) Clinical signs of infection along with a negative gram stain suggest either an extrapulmonary source of infection or sterile inflammation (e.g., intracranial hemorrhage).

> Empiric broad-spectrum antimicrobial therapy was initiated for the case patient following sampling of the lower respiratory tract due to a high degree of clinical suspicion (fever, leukocytosis, new infiltrate on CXR, and purulent secretions visualized on bronchoscopy), transient hemodynamic instability, and organisms visualized on gram stain.

The primary concern when treating VAP is the administration of "adequate therapy," being collectively at least one antimicrobial agent to which the pathogen is sensitive, in the correct dose, via the correct route of administration, and in a timely manner. A second crucial aspect of VAP therapy involves serial reevaluation and interpretation of initial microbiology so that (1) therapy may be discontinued if no organism is isolated and the patient has not deteriorated clinically; (2) therapy is deescalated to treat only the specific etiologic pathogen; and (3) an endpoint of therapy may be identified and adhered to in prospect.

Ample data exist detailing the increased mortality associated with inadequate initial antimicrobial therapy in patients with VAP. Iregui et al. showed that delayed therapy (defined as initial antibiotic treatment administered ≥ 24 h after meeting diagnostic criteria for VAP) was independently associated with hospital mortality (OR 7.68, 95% CI 4.50–13.09, $p < 0.001$).(132) The mean difference in time to antibiotic administration between groups was 16 h. Similarly, Kollef et al. reported that inadequate initial antimicrobial therapy was an independent risk factor for ICU mortality in patients with gram-negative infections (OR 4.22, 95% CI 3.57–4.98, $p < 0.001$).(25) Alvarez-Lerma et al. demonstrated that attributable mortality from VAP was significantly lower among patients receiving initial appropriate antibiotic treatment compared with receipt of inappropriate treatment (16.2% vs. 24.7%; $p = 0.03$).(104) That appropriate initial therapy is essential is underscored by the fact that Alvarez-Lerma et al. demonstrated that switching to appropriate therapy once culture results became available did not ameliorate the excess mortality associated with inadequate initial therapy.

> Piperacillin-tazobactam and vancomycin were initiated empirically in the case patient, in order to provide adequate coverage against all likely pathogens associated with VAP in this setting, including MRSA and Pseudomonas.

Choice of initial antimicrobial therapy depends on patient risk factors for MDRO pathogens (Table 25.2) and local microbiologic data that may be obtained from the unit-specific antibiogram. Having a current and frequently updated antibiogram increases the likelihood that appropriate initial antibiotic treatment will be prescribed.(134–136) In general, therapy for patients at risk for infection with an MDRO should provide coverage against MRSA, *Pseudomonas*, *Acinetobacter*, and extended-spectrum β-lactamase-producing *Klebsiella* and *E. coli*. This will likely require at least two drugs, one effective against MRSA (e.g., vancomycin, linezolid) and one effective against MDR gram-negative bacilli, particularly *Pseudomonas* (e.g., piperacillin-tazobactam, meropenem). Patients with early onset VAP (occurring < 5 days after intubation) and none of the aforementioned risk factors may be treated with narrow-spectrum therapy.

Antimicrobial therapy for VAP should be administered initially via the intravenous (IV) route. Enteral therapy may be considered if patients demonstrate an adequate response to IV therapy, gastrointestinal function is normal, and the antibiotics used

Table 25.2 Risk Factors for VAP with MDRO

Late-onset VAP (occurring ≥ 5 days after intubation)
Antibiotics within previous 90 days
Hospitalization within previous 90 days
Current hospitalization > 5 days
Admission from a long-term care/hemodialysis facility
High frequency of antibiotic resistance in the community
Immunosuppressive disease or therapy

possess equivalent bioavailability when administered via this route. Conversion to enteral therapy for VAP using either linezolid or a fluoroquinolone is effective, assuming the aforementioned criteria are met.(137) An RCT of the adjunctive use of aerosolized tobramycin showed no difference in clinical outcomes between groups, despite significantly increased microbiologic eradication in the tobramycin group (138); further research into the use of aerosolized antibiotics is needed.

Inadequate dosing of antibiotics leads to the emergence of MDR bacteria and is associated with poorer outcomes in VAP.(139) Appropriate initial dosing of vancomycin (15 mg/kg q12h) and aminoglycosides (gentamicin or tobramycin 7 mg/kg once daily; amikacin 20 mg/kg once daily). Increasing resistance to fluoroquinolones (levofloxacin 750 mg/day, ciprofloxacin 400 mg q8h) makes their empiric use increasingly dubious.

Certain points regarding specific antibiotics warrant further discussion. Most notably, linezolid has emerged as an effective alternative therapy for VAP caused by gram-positive bacteria, and MRSA in particular. Linezolid is theoretically appealing for the treatment of VAP because achievable concentrations in bronchial secretions exceed those in serum, dosing adjustment is not needed for renal failure, and enteral administration has equivalent bioavailability.(140) Two RCTs demonstrated clinical equivalence of linezolid and vancomycin in the treatment of VAP caused by gram-positive pathogens (141, 142), and a post hoc logistic regression analysis of both studies reported a significantly increased likelihood of clinical cure for linezolid therapy as compared to vancomycin.(143) One limitation of these studies involves the possible inadequate initial dosing of vancomycin (1 g q12h vs. the currently recommended 15 mg/kg q12h). However, linezolid is at least as effective as vancomycin in the treatment of gram-positive VAP, and specifically MRSA infections. Recent cost-effectiveness analyses have also demonstrated significant cost savings associated with the use of linezolid as compared to vancomycin.(144, 145)

Abundant data now exist documenting the association between prior fluoroquinolone use and the emergence of VAP caused by MDRO pathogens, particularly MRSA and *Pseudomonas*.(146–148) Fluoroquinolone use in the treatment of VAP should therefore be judicious, based on frequently updated institutional antibiograms. Whereas multidrug therapy is usually necessary to achieve adequate empiric coverage in patients with suspected VAP until culture results become available, combination therapy directed against a specific pathogen (e.g., "double coverage" of *Pseudomonas*) is unlikely to provide benefit and may worsen outcomes. Neither in vitro nor in vivo synergy of such combination therapy has been demonstrated consistently.(149, 150) A meta-analysis of all trials of β-lactam monotherapy vs. β-lactam–aminoglycoside combination therapy for immunocompetent patients with sepsis, including 64 trials and 7,586 patients, found no difference in either mortality (relative risk 0.90, 95% CI 0.77–1.06) or the development of resistance.(151) In fact, clinical failure was more common with combination therapy, as was acute kidney injury.

Following initiation of adequate antimicrobial therapy for suspected VAP, results of lower respiratory tract cultures may reveal (1) no growth or insignificant growth (below the predetermined threshold value); (2) significant (above threshold) growth of a pathogen sensitive to a narrow-spectrum agent; or (3) significant growth of a pathogen sensitive only to a broad-spectrum agent. Regarding the first scenario, data indicate that antimicrobial therapy may be discontinued safely as long as the patient has not deteriorated clinically.(129–132) In the second scenario, therapy is deescalated to a narrow-spectrum agent with activity against the pathogen isolated. In the last scenario, the initial broad-spectrum agent to which the pathogen is susceptible is continued.

The goal of adequate empiric therapy is to initiate a combination of antibiotics likely to cover all possible etiologic pathogens, followed by tailored therapy if possible. The ideal treatment of suspected VAP thus involves both an initial period of perfect sensitivity followed by a period of perfect specificity, once microbiology results are available. In this fashion, no patient with VAP is untreated, and no patient without VAP is treated after microbiologic data are available.

> In the case patient, piperacillin-tazobactam therapy was discontinued after 48 h once the pathogen was identified as MRSA, whereas vancomycin was continued.

Once pathogen-specific therapy has been initiated, its duration must be determined such that prolonged and unnecessary periods of antibiotic administration are avoided. Resolution of clinical and radiographic parameters typically lags the eradication of infection.(152) Vidaur et al. found that improved oxygenation and normalization of temperature occurred within 3 days in VAP patients without ARDS.(121) Dennesen et al. observed a clinical response to therapy of VAP, defined as normalization of temperature, WBC count, arterial oxygen saturation, and quality of tracheal aspirates, within 6 days of therapy.(153)

A randomized, multicenter trial of 401 patients with microbiologically proved VAP assigned subjects to receive either 8 or 15 days of antibiotic therapy.(154) All patients received adequate initial therapy after invasive/quantitative specimen collection and analysis, and patients whose therapy ended at 8 days were stable clinically at that time. Patients treated for 8 days had equivalent mortality, ICU LOS, duration of mechanical ventilation, and recurrence of infection despite significantly more antibiotic-free days. Recurrent infections were less likely to be caused by MDRO pathogens in patients treated for 8 days. However, patients with VAP caused by nonfermenting gram-negative bacilli (e.g., *Pseudomonas, Acinetobacter, Stenotrophomonas*) were more likely to develop recurrent pneumonia if treated for 8 days only. Thus, an 8-day course of initially appropriate antimicrobial therapy appears safe and effective provided that the patient has not deteriorated and possibly if the pathogen is not a nonfermenting gram-negative bacillus.

> Given clinical stability and the absence of nonfermenting gram-negative bacilli as an etiologic agent, antibiotic therapy was discontinued following 8 days in the case patient.
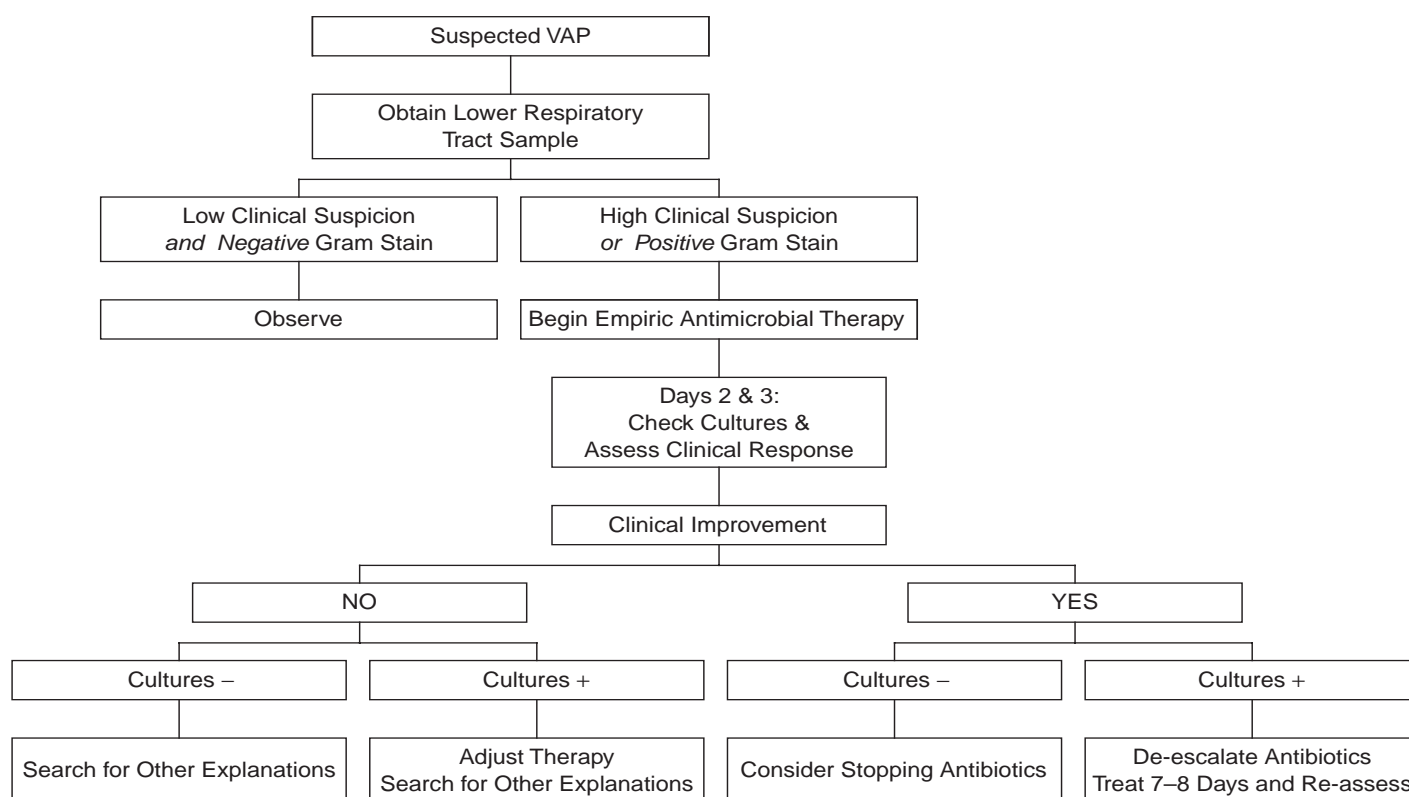
Figure 25.1 VAP management algorithm

In select patients, a shorter course of therapy may be effective for the treatment of VAP. Singh et al. randomized patients with suspected VAP and a CPIS score ≤ 6 points to receive either standard therapy (physician discretion) or ciprofloxacin monotherapy, with reevaluation at day 3 and discontinuation of antibiotics if the CPIS remained ≤ 6.(112) If the CPIS remained ≤ 6 at the 3-day evaluation point, antibiotics were continued in 96% (24/25) in the standard therapy group, but in none of the patients in the experimental therapy group (*p* = 0.0001). Mortality and ICU LOS did not differ despite a shorter duration (*p* = 0.0001) and lower cost (*p* = 0.003) of antimicrobial therapy in the experimental arm.

Patients treated for VAP who do not improve clinically after appropriate antimicrobial therapy pose a dilemma. Inadequate therapy, misdiagnosis, or a pneumonia-related complication (e.g., empyema or lung abscess) must be considered. A diagnostic evaluation should be repeated, including resampling of the lower respiratory tract for quantitative cultures (using a lower diagnostic threshold when interpreting quantitative microbiology given recent antibiotic exposure) and consideration of broadened coverage until new data become available. An algorithm for the evaluation and management of the patient with suspected VAP is shown in Figure 25.1.

Current literature suggests a discrepancy between the principles of care discussed herein and contemporary clinical practice. Rello et al. reported that in a cohort of 113 patients with VAP, nearly 25% received inadequate initial therapy.(155) In a second cohort study of 398 ICU patients with suspected VAP from 20 ICUs throughout the United States, Kollef et al. documented more than 100 different antibiotic regimens prescribed as initial therapy of VAP.

(22) Furthermore, the mean duration of therapy was 11.8±5.9 days, and in 61.6% of cases there was neither escalation nor deescalation. The use of standardized treatment protocols can improve substantially the likelihood that adequate therapy is delivered for an appropriate duration. Ibrahim et al. compared outcomes before and after implementation of a VAP treatment protocol that involved standardized, broad-spectrum initial coverage, with termination after 7 days absent persistent signs of active infection.(134) The proportions of patients who received inadequate initial therapy and therapy of inappropriate duration were significantly lower in the protocol arm. Several additional studies have confirmed the effectiveness of protocol-driven therapy.(156, 157)

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26 Acute respiratory distress syndrome
Nabil Issa and Michael Shapiro

A 20-year-old victim of a motor vehicle crash was presented to the surgical intensive care unit (SICU) after a damage control laparotomy. He was resuscitated to a heart rate of 100/min and systolic blood pressure of 120 mmHg with crystalloids and blood products. The ventilator mode of ventilation was chosen as Synchronized Intermittent Mandatory Ventilation (SIMV), at a rate of 12 breaths/min, tidal volume (V_t) 800 mL, PEEP 5 cm, and FiO2 50%. The next day, after reversal of acidosis, hypothermia, and coagulopathy, the patient was returned to the operating room for removal of packs and fascial closure. A few days later, the patient became hypoxemic, despite escalating FiO_2 and PEEP support. Chest X-ray showed fluffy bilateral infiltrates and moderate pleural effusions. The PO2/FiO2 ratio was 120. Tidal volumes were changed to 6 cc/kg V_t, and FiO_2 and PEEP were incrementally increased to provide a PO2 > 60 mmHg, while maintaining plateau pressure (P_{pl}) < 30 mmHg. Diuresis was initiated. Due to continued dyssynchrony with the ventilator, neuromuscular paralysis was initiated. Due to persistent hypoxemia in spite of significant FiO_2 and PEEP escalation, inhaled nitric oxide Inhaled nitric oxide (iNO) was added, and the patient was turned in the prone position. Gradual improvement in oxygenation and ventilation was noted over the next 6 days. INO was stopped, and rotational therapy discontinued. The patient was successfully weaned from mechanical ventilation and extubated on SICU day 13.

ACUTE LUNG INJURY AND ACUTE RESPIRATORY DISTRESS SYNDROME

Definitions
Acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) constitute the major reason for acute respiratory failure in the surgical population, including trauma. The American–European Consensus Committee on ARDS in 1994 defined ALI as a syndrome of pulmonary inflammation and increased capillary permeability that is associated with a constellation of clinical, radiological, and physiological abnormalities that cannot be explained by, but may coexist with, left atrial failure or pulmonary capillary hypertension.(1) The clinical criteria for ALI are acute respiratory failure with a PaO2/FiO2 ratio < 300 mmHg, bilateral lung infiltrates visible on CXR, and a pulmonary artery occlusion pressure (PAOP) < 18 mmHg or no clinical evidence of increased left atrial pressure. ARDS is a more severe form of ALI representing the advanced manifestation of the loss of functional and structural integrity of the lungs. It shares the same clinical criteria with ALI except that the ratio of PaO2/FiO2 is < 200 mmHg, regardless of the positive end-expiratory pressure (PEEP) level used on the mechanical ventilator.

Epidemiology
About 5–15% of patients admitted to intensive care units (ICUs) across the USA are diagnosed with ALI/ARDS, an estimated 190,600 cases annually. With better understanding of the disease process and the recent advancement of ventilatory and systemic support, the mortality rates have been noted to decrease from an estimated 60% in the 1980s (2, 3), to 38% quoted in the latest estimates. In spite of these advances, the added costs of caring for patients with ALI/ARDS are estimated to be in excess of $7 billion dollars/year.(4, 5)

Most deaths in ARDS are attributable to sepsis or multiorgan failure (MOF) rather than actual pulmonary failure. Other risk factors noted for increased mortality in ARDS are advanced age, chronic liver disease, extrapulmonary organ dysfunction, and sepsis.(6)

Major long-term consequences of lung injury are related to neuromuscular, cognitive, and psychological dysfunction. Surprisingly, long-term pulmonary dysfunction occurs to a lesser degree in survivors.(7–10)

Pathophysiology
ARDS has three distinctive pathological phases: an early exudative phase followed by a proliferative phase and lastly a fibrotic phase.(11) The exudative phase is characterized by increased capillary permeability and accumulation of proteinaceous fluid in alveolar spaces. Physiologically, large proportions of lung alveoli become consolidated and are not available for gas exchange. This results in a functionally smaller lung with significant hypoxemia and hypercarbia. Hypoxemia may further aggravate parenchymal lung injury, resulting in significant systemic inflammatory response syndrome and increased potential for multiorgan dysfunction. Of note, these seemingly diffuse parenchymal injuries actually have marked regional differences in the degree of inflammation present, and thus the degree of mechanical and functional abnormalities that exist.(12) Most patients recover from this phase within a week. If resolution does not happen, the disease progresses into the proliferative phase. Connective tissue and structural elements in the lungs proliferate in response to the initial injury, and lung tissue appears densely cellular under microscopy; this stage typically lasts 3–10 weeks. In the third or fibrotic phase, resolution of inflammation and excess cellularity is coupled with the manifestation of excess fibrosis and destruction of lung parenchyma seen as enlarged air spaces throughout the lung. The extent of fibrosis in excess of healing determines the patient's functional outcome.

Ventilator-Induced Lung Injury (VILI)
Mechanical ventilation can be injurious to already compromised lungs. Several patterns of injury are now recognized. "Barotrauma" describes air leaks from damaged alveoli causing pneumothorax,
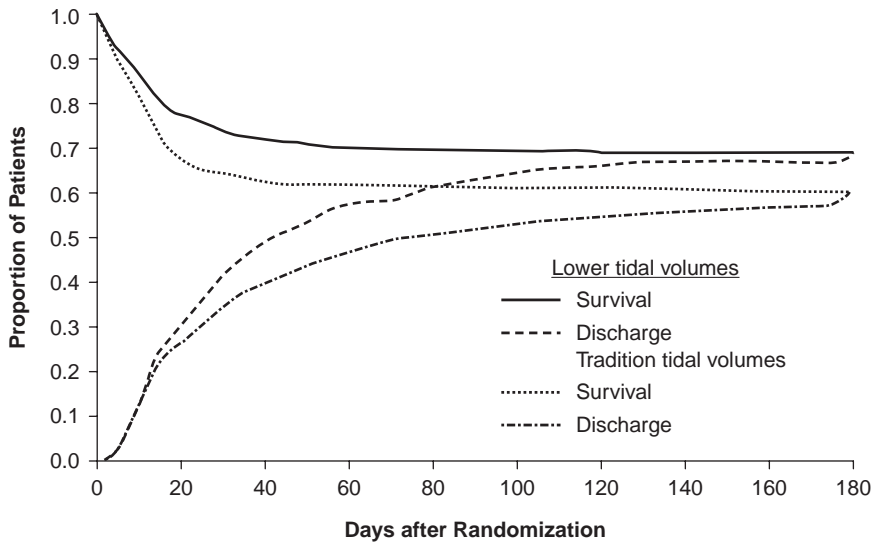
Figure 26.1 Probability of survival and of being discharged home, breathing without assistance during the first 180 days After Randomization in patients with ALI and the ARDS.

[The Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 2000; 342:1301–08](25).
*Legal Permission Obtained from the Publisher.

pneumomediastinum, and subcutaneous emphysema. This is recognized in approximately 13% of ARDS patients, with an estimated mortality < 2%.(13, 14) High levels of PEEP are associated with barotrauma, but not elevated mean or peak airway or plateau pressures.(15) "Volutrauma" describes an alveolar over-stretch mechanism of injury. This may happen when large volume breaths are used in functionally small lungs, resulting in over-distention of alveoli and causing injury to the alveolar pneumocytes, microvascular injury, and worsening of pulmonary edema.(16) "Atelectrauma" results from repeated cycles of recruitment and derecruitment of the alveoli, with a resulting mechanical wear and tear of the alveolar walls. "Biotrauma" is caused by alveolar inflammatory response secondary to hypoxemia of alveolar macrophages and pneumocytes. These cells will release local and systemic mediators, including tumor necrosis factor [TNF]-α, interleukin (IL-6, IL-8, and IL-10) (17–19)—all shown to be associated with increased morbidity and mortality in ARDS patients.(20)

Treatment of Acute Respiratory Distress Syndrome

The treatment of ALI and ARDS requires supportive care. This includes source control and treatment of sepsis, nutritional support, controlled fluid management, and prevention of intervening medical complications. Appropriate mechanical ventilatory strategy is of paramount importance to support ALI/ARDS patients.

LOW-STRETCH VENTILATION

Low-stretch ventilation describes a strategy designed to reduce alveolar wall tension. The American College of Chest Physicians consensus conference on mechanical ventilation in 1993 recommended maintaining the inspiratory pressure less than 35 cm H2O in patients with ARDS.(21) This recommendation was based on observations in human subjects as well as animal models of VILI. In normal human volunteers, the distending lung pressure at total lung capacity, representing the alveolar plateau pressure, is measured to be 37 cm H2O, although this may not be sustainable with repeated full inspirations.(22) In animal models of VILI, plateau pressures of 30–35 cm H2O, depending on the species, are associated with the development of lung injury.(23–25)

Between 1996 and 1999, the National Heart, Lung, and Blood Institute ARDS-Network conducted a multicenter, randomized, controlled trial for ALI/ARDS patients and compared a "high-stretch" ventilation strategy (initial tidal volume 12 mL/kg ideal body weight, adjusted to maintain $P_{pl} \leq 50$ cm H_2O) with a "low-stretch" strategy (initial tidal volume 6 mL/kg ideal body weight, adjusted to maintain $P_{pl} < 30$ cm H_2O). The trial demonstrated significant advantages in favor of the "low-stretch" strategy. In-hospital mortality was reduced to 31 vs. 40%, respectively; $p = 0.007$ (Figure 26.1). The number of ventilator-free days in the first 28 days was higher in the group treated with lower tidal volumes as was the number of days without failure of non-pulmonary organ systems. There was demonstrable reduction in inflammatory cytokines, IL-6, IL-8, and IL-10 in patients managed with low tidal volume (20), suggesting significant attenuation of the inflammatory response in those patients. As a result of this trial, low-stretch ventilation has become the standard of care in the ventilator management of patients with ALI/ARDS.

Sedation Requirements During Low-Stretch Ventilation

Early concerns that a low tidal volume strategy would increase the use of sedatives and narcotics have not been supported. A secondary analysis of patients who participated in the original ARDS-Network trial for low tidal volume ventilation showed no significant differences in the percentage of study days in which patients received sedatives, opioids, or neuromuscular blockade, nor were there any difference in the amount of drugs given. Other studies confirmed those findings.(26–28)

The creation of respiratory therapist and nurse-driven sedation algorithms and ventilator weaning protocols has been shown to improve patient outcomes including decreased mortality rates and decreased the incidence of ventilator-associated pneumonia (VAP) in those patients.(29, 30) The implementation of such protocols has also been shown to cut costs and improve ICU resource utilization through significant decrease in length of stay on the ventilator, in length of stay in the ICU, and in length of stay in the hospital. (31, 32)
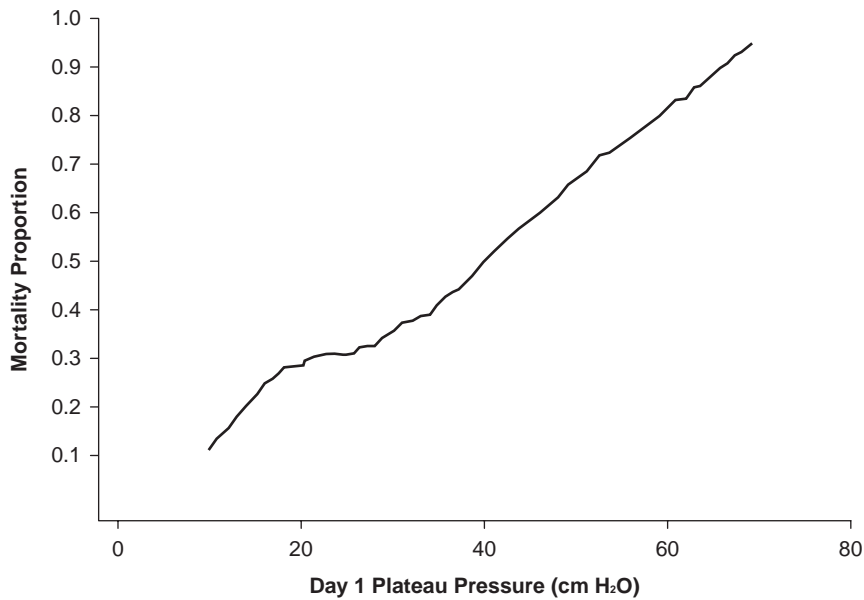
Figure 26.2 Robust locally weighted regression and smoothing (Lowess) plot (Bandwidth, 0.4) of mortality and day 1 plateau pressure (Ppl; cm H2O) among patients enrolled in the ARDS network study (n = 787) showing the linear increase in mortality with increased plateau pressures.

Source: (35), (29).
*Legal permission obtained from the publisher.
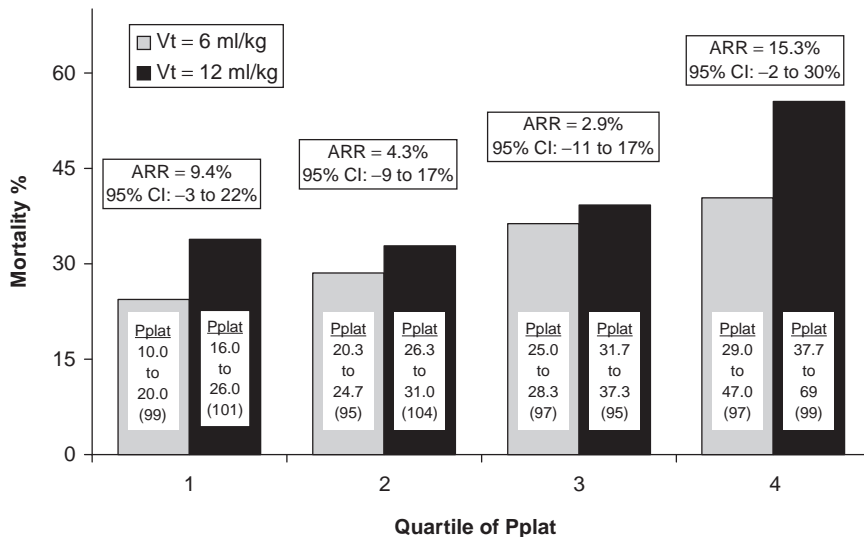
Figure 26.3 Mortality difference by quartile of day 1 P_{pl}. The range of P_{pl} levels in cm H_2O and the number of patients (n) is detailed in each bar of the graph. ARR = Absolute Risk Reduction; CI = Confidence Interval.

Source: (35), (29).
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Low Tidal Volume (V_t) Versus Low Plateau Pressure (P_{pl})

Questions were raised after the ARDS-Network publication as to whether the favorable outcomes were mainly due to the limitation of tidal volume or plateau pressure. No actual trials were designed to test this theory, but a meta-analysis conducted in 2002 that included all low vs. high tidal volume ARDS trials argued that lower plateau pressures alone would be an adequate target, independent of the tidal volume used (33). The analysis also suggested that using a tidal volume of 6 mL/kg ideal body weight could be problematic in patients who had already achieved an inspiratory plateau pressure of 28–32 cm H2O (Figure 26.2)

A counterargument was presented after analyzing outcomes at different quartiles of plateau pressure levels from the original ARDS-Network low tidal volumes trial (34) (Figure 26.3). This analysis demonstrated a beneficial effect of using low tidal volume ventilation in all quartiles of plateau pressure. This suggested that benefit is gained by the absolute tidal volume reduction more than plateau pressure adjustments.

Until further evidence is presented, the standard of care for ventilator management of patients with ALI/ARDS should include maintaining both a tidal volume ≤ 6 mL/kg ideal body weight and a plateau pressure less than 30 cm H2O.

HIGH PEEP VERSUS LOW PEEP

Positive end-expiratory pressure (PEEP) is an essential component of mechanical ventilation for patients with ARDS. PEEP recruits alveoli, increasing the functional residual capacity and leading to improved oxygenation. In inadequately resuscitated patients, higher PEEP is associated with hypotension, as it interferes with blood return to the right atrium.

"Open lung ventilation" describes an approach in which high PEEP is applied to splint the alveoli open and prevent cyclical recruitment/derecruitment injury. Strategies that include higher PEEP levels have been associated with better survival and lower levels of inflammatory mediators in plasma and bronchoalveolar lavage fluid .(27, 35) However, in those trials patients who

received higher PEEP levels also received lower tidal volumes and maintained lower inspiratory airway pressures, making it unclear whether the better outcomes resulted from the higher PEEP levels, the lower tidal volumes and airway pressures, or both. The question was further studied in the 2004 ARDS-Network trial, Assessment of Low Tidal Volume and Elevated End-Expiratory Pressure to Obviate Lung Injury, known as the ALVEOLI Trial.(36) ARDS patients were randomized to a ventilatory protocol utilizing high or low levels of PEEP in predetermined steps to achieve an oxygen saturation (SpO2) of 88–95%, measured by pulse oximetry or PaO2 of 55–80 mmHg measured through arterial blood gas. All patients were ventilated with low tidal volumes (6 mL/kg ideal body weight) and maintained plateau pressures below 30 cm H2O. There was no difference in mortality rate between the two groups (24.9% in the low PEEP group vs. 27.5% in the high PEEP group). Length of ventilator support, in-hospital mortality rate, and the duration of non-pulmonary organ failure were similar between the two groups. These results suggested that in patients with ALI/ARDS who receive mechanical ventilation with a tidal volume goal of 6 mL/kg ideal body weight and maintain a plateau pressure limit of 30 cm, clinical outcomes are similar whether lower or higher PEEP levels are used.

Similar findings were reported in a multicenter, multinational, randomized controlled trial of 983 ARDS patients set to examine the effect on mortality of the open lung ventilation strategy. The protocol included simultaneous application of low tidal volume ventilation, recruitment maneuvers, and high levels of PEEP. This open lung approach was compared to the established low tidal volume strategy in patients with ALI/ARDS.(37) The study showed no significant difference in all-cause hospital mortality or incidence of barotrauma between the two groups.

PERMISSIVE HYPERCAPNIA

Permissive hypercapnia is a lung protective, low tidal volume strategy in which elevated PaCO2 is tolerated, and the consequent respiratory acidosis is medically managed. This is an alternative to employing high tidal volume and high pressure to achieve eucapnia in patients with ALI/ARDS.(38, 39)

The safety of hypercapnia was demonstrated in several studies (40–42), and several investigators have shown favorable anti-inflammatory and antioxidative effects of hypercapnia in hypoxic and inflammatory conditions in models of ALI and organ injury.(43–45) Furthermore, a protective effect of hypercapnic acidosis against ventilator-induced lung injury was noted during a secondary analysis of data from the ARDS-Network trial.(46) Using hypothesis-driven multivariate logistic regression, investigators found that hypercapnic acidosis was associated with reduced 28-day mortality in the high tidal volume group (12 mL/kg) after controlling for comorbidities and severity of lung injury. The protective effect of hypercapnia was not noted in patients managed with low tidal volume. This suggested that permissive hypercapnia can be protective in patients with continued exposure to high tidal volumes.

FLUID MANAGEMENT RECOMMENDATIONS

ARDS represents noncardiogenic pulmonary edema secondary to leaky alveolo-capillary units. Appropriate fluid management is mandatory to improve patient outcome. Prevention and treatment of edema are essential to improve oxygenation recover lung function. Under-resuscitation, however, may result in hypotension and circulatory shock with renal failure and subsequent MOF.

The role of fluid management in ARDS patients was assessed in the ARDS-Network, Fluid and Catheter Treatment Trial, known as FACTT trial.(47) One thousand ALI/ARDS patients were randomized to either conservative or liberal use of fluids under strict invasive hemodynamic monitoring. Patients received furosemide or fluids to move their intravascular pressure toward the target range. In the liberal-strategy group, a goal central venous pressure (CVP)10–14 mmHg or PAOP14–18 mmHg was chosen; while in the conservative-strategy group, the goal CVP was less than 4 mmHg or PAOP less than 8 mmHg. The cumulative fluid balance for the first 7 days was significantly different between the two groups. In the restrictive group, a negative balance of 140 mL was achieved, as compared to a positive balance of 7 L in the liberal group. As compared to the liberal strategy, the conservative strategy improved oxygenation and allowed for faster ventilator weaning and earlier discharge from the ICU. The conservative strategy did not increase the incidence or duration of shock or the number of non-pulmonary organ failures during the study period or the use of dialysis. However, there was no statistical difference in the 60-day all-cause mortality between the two groups. These results support the use of a conservative strategy of fluid management in patients with ALI/ARDS. While there remains no evidence to support improved outcomes, it is the authors' strong bias that pulmonary artery catheters, which offer continuous assessment of cardiac function and mixed-venous oxygen saturation, are of value in managing patients with ARDS.

UNCONVENTIONAL SUPPORT FOR ACUTE RESPIRATORY DISTRESS SYNDROME

Numerous strategies have been proposed for the management of patients with severe respiratory failure, deteriorating in spite of optimal ventilatory support. These include different ventilator modalities, positional changes, and pharmacological interventions. Most of these strategies have been shown to improve oxygenation and patient/ventilator synchrony in some patients, but none has been proved to alter disease course or improve overall patient outcomes. In many cases, these interventions have been thought of as added support measures that may help stabilize the patient's condition, until being able to resume support with more conventional modes.

[1] Inverse ratio ventilation (IRV) and airway pressure release ventilation (APRV)

The normal inspiratory to expiratory ratio (I/E) during spontaneous breathing is 1:2 to 1:3. This ratio can be manipulated during mechanical ventilation in both volume- and pressure-cycled modes. Inverse ratio ventilation prolongs the inspiratory phase, sustaining alveolar inflation and thereby improving oxygenation. Heavy sedation and possibly paralysis are required. At high respiratory rates, if there is insufficient time to complete exhalation, intrinsic PEEP ("auto-PEEP") may further complicate gas exchange.

APRV is a pressure-limited, time-cycled mode of mechanical ventilation that allows the patient unrestricted spontaneous breathing. APRV uses high continuous airway pressure to promote alveolar recruitment and maintain adequate lung volume. A time-cycled release phase to a lower pressure ensures adequate minute ventilation.(48) Unrestricted spontaneous breathing throughout the ventilator cycle APRV, in theory, allows for better ventilation of dependent lung regions. Spontaneous breathing reduces atelectasis and improves end-expiratory lung volume during lung injury.(49) There is substantial anecdotal support for the use of IRV and APRV in patients with ARDS. There are, however, no randomized controlled trials demonstrating IRV or APRV efficacy in ARDS patients in terms of mortality, duration of mechanical ventilation, and lengths of stay in the ICU and in the hospital. Many practitioners find these modes theoretically appealing, but due to the lack of supremacy over other modes their routine use is not recommended.

[2] Prone positioning

Prone positioning models use gravitational forces to manage interstitial lung edema and allow for decreased intrapulmonary shunting. Change in patient position improves oxygenation by optimizing ventilation/perfusion matching and by promoting alveolar recruitment. (50) Despite consistently demonstrating short-term improvements in oxygenation, prone positioning during mechanical ventilation has failed to improve mortality rates in multiple randomized controlled trials.(51–53) Complications of endotracheal tube or vascular catheter dislodgement are feared but do not clearly happen at an increased rate. This issue may become moot as the procedure for turning the patient prone has become technically simpler with the development of mechanical rotating beds.

[3] Inhaled nitric oxide

INO is a selective pulmonary vasodilator, resulting in decreased pulmonary vascular resistance, pulmonary arterial pressure, and right ventricular afterload. The selectivity of nitric oxide (NO) for the pulmonary circulation is the result of rapid hemoglobin-mediated inactivation of NO. Low-dose INO in ALI/ARDS patients has been associated with improved short-term oxygenation. This did not, however, translate into decreased duration of mechanical ventilation or mortality.(54, 55) Furthermore, although around 60% of patients who receive inhaled NO responded clinically with improved oxygenation, these benefits are typically short-lived, fading after the first few (1–2) days of administration. In the authors' experience, it is difficult to predict which patients will respond to INO, and several patients have demonstrated remarkable improvement. INO is, therefore, used as part of a coordinated treatment approach. Because it is relatively expensive, it is discontinued if the patient does not demonstrate a response within 4 h of initiating therapy.

[4] High-frequency oscillatory ventilation (HFOV)

HFOV uses a piston pump-driven diaphragm to deliver small tidal volumes of gas, thereby limiting alveolar over distension, while maintaining high mean airway pressure. This prevents cyclical derecruitment of the lung.

While numerous anecdotal reports and small case series have described the use of HFOV in adults, outcome benefits have not been proven in large prospective, randomized trials.(56–58) The Multicenter Oscillatory Ventilation for Acute Respiratory Distress Syndrome Trial (the MOAT trial) compared HFOV with a pressure-controlled ventilation strategy ($n = 148$). HFOV was associated with early improvement in oxygenation as compared with the conventional ventilation group; however, this difference did not persist beyond 24 h. Oxygenation decreased similarly during the first 72 h in both groups. Thirty-day mortality was not significantly affected (37% in the HFOV group vs. 52% in the conventional ventilation group, $p = 0.1$). No differences were identified in the percentage of patients alive without mechanical ventilation at day 30 (36% HFOV vs. 31% conventional, $p = 0.7$). There were no significant differences in hemodynamic variables, oxygenation or ventilation failure, barotrauma, or mucus plugging between the two groups.

Similarly, a review of the clinical experience with HFOV in Toronto ($n = 156$) in patients with severe ARDS (mean PaO2/FiO2 ratio, 91 ± 48 mmHg) concluded that HFOV had beneficial effects on oxygenation and may be an effective rescue therapy for adults with severe hypoxemia and that the early institution of HFOV may be advantageous.(60, 61)

[5] Corticosteroids

Steroid use in ARDS remains controversial. Persistent ARDS is characterized by inflammation, cellular proliferation, and disordered deposition of collagen. There is sustained interest in the potential application of the anti-inflammatory properties of corticosteroid therapy to this disease process. Several trials of high-dose, short-course corticosteroids for early-phase ARDS failed to show improvements in survival.(62–65) In 2007, a randomized, controlled study of 91 patients in early ARDS (within 3 days of diagnosis) were randomized to low-dose long-course methylprednisolone vs. placebo and adopted a more gradual tapering policy of the steroids. In this trial, glucocorticoid treatment was associated with down-regulation of markers of systemic inflammation and was associated with significant improvement in pulmonary and extrapulmonary organ dysfunction. It also showed a reduction in the total duration of mechanical ventilation and ICU length of stay. The authors stressed the importance of long and gradual tapering of steroids in achieving the desired results.(66)

To assess the effects of steroids on patients with late-stage ARDS, an ARDS-Network double-blinded, randomized trial (67) enrolled 180 patients diagnosed with ARDS for at least 7 days. The patients were randomly assigned to receive low-dose methylprednisolone for 21 days vs. placebo. The steroids were tapered over 2–4 days. Methylprednisolone increased the number of ventilator-free and shock-free days during the first 28 days with improvemen t in oxygenation, respiratory-system compliance, and blood pressure readings, including fewer days of vasopressor therapy. There was no increase in the rate of infectious complications, but there was a higher rate of neuromuscular weakness among patients treated with the steroid. The major adverse event encountered was increased mortality rates in patients treated with

methylprednisolone. That mortality rate increase was mainly noted in those patients enrolled at least 14 days after the onset of ARDS.

Discrepancies in patient characteristics and steroid dosing and tapering schemes contributed to the conflicting results and observations in different studies. Until conclusive results are reached, the use of steroids after 14 days of diagnosing ARDS is not recommended as it is associated with increased mortality. The use of steroids in early ARDS remains controversial.

[6] Extracorporeal membrane oxygenation (ECMO)

ECMO is a proven modality for the treatment of severe cardiorespiratory failure in the neonate.(68) Its use in adults with cardiac arrest has been shown to achieve favorable outcomes.(69, 70) However, the utilization of ECMO for patients with severe but potentially reversible respiratory failure including ARDS remains controversial. This is mainly due to the high technical demands, long learning curve, significant cost, and risk of complications, especially bleeding. Multiple reports have indicated a possible benefit for its use to salvage those patients failing aggressive conventional therapy.(71) In the United Kingdom, a randomized controlled trial to compare conventional ventilatory support vs. extracorporeal membrane oxygenation for severe adult respiratory failure, the CESAR Trial (72), recruited 180 patients, 90 in each arm of the study, the largest to date. The primary outcome measure was death or severe disability 6 months after randomization and included deaths before hospital discharge if occurring after 6 months. Severe disability was defined as being both confined to bed and unable to wash or dress oneself. More than 50% of patients in both arms of the study were diagnosed with pneumonia at the time of recruitment, and more than 25% of patients in both groups had more than three associated organ failures. Of the patients randomly assigned to receive ECMO, 57 of 90 met the primary end point of survival or absence of severe disability at 6 months compared with 41 of 87 patients in the conventional ventilation group, a relative risk in favor of the ECMO group of 0.69 (95% confidence interval, 0.05–0.97; $p = 0.03$). In the intent-to-treat analysis at 6 months, ECMO was associated with 31% lower incidence of the combined primary outcome of death or severe disability than conventional ventilation (relative risk 0.69, 95% confidence interval 0.05–0.97, $p = 0.03$). The investigators recommended ECMO for patients who failed lung-protective ventilation and stressed that it should be implemented as early as possible as there would be no advantages if applied after 10 days of the start of the disease process. However, due to the cost and significant resource utilization demands, ECMO for adults is available in few centers across the country.

[7] Surfactant

Pulmonary surfactant is a lipoprotein complex formed naturally by type II alveolar pneumocytes. Due to the specific physiochemical arrangement of the protein and lipid elements of the compound, the surfactant coats the alveolar lumen and is responsible for reducing the surface tension of the alveolar wall. The presence of surfactant prevents alveolar collapse at the end of expiration and is responsible for the appropriate compliance of the lungs. Surfactant system dysfunction, and even total loss, is a constant finding in ARDS patients. Exogenous surfactant therapy is an effective standard of care, improving both oxygenation and mortality in neonates diagnosed with ARDS.(73–75) Some studies have shown that exogenous surfactant may improve oxygenation in adults with ARDS (76, 77), but all clinical studies to date have demonstrated no significant effect on the death rate or length of use of mechanical ventilation in the adult population. Further studies are required in the adult population before incorporating this modality in the management of adult patients diagnosed with ARDS.

[8] Novel potential therapies for ARDS

Activated protein C (APC) has proven anti-inflammatory, fibrinolytic, and antithrombotic effects and has been demonstrated to significantly reduce mortality in patients with systemic severe sepsis.(78) The basic inflammatory processes occurring in the lungs during ARDS involve thrombosis with capillary occlusion, leaky endothelium, and fibrin-rich exudative reaction. As such, the potential utilization of APC in ARDS is being evaluated in an ARDS-Network multicenter phase II trial in patients with ALI.

Granulocyte–macrophage colony-stimulating factor (GM-CSF) plays an important role in the development and homeostasis of alveolar macrophages as well as in the prevention of apoptosis in alveolar epithelium and is currently being evaluated for a possible therapeutic role in ALI/ARDS.(79, 80)

Alveolar fluid clearance is a critical component for the resolution of lung injury. β-Agonists accelerate alveolar fluid clearance and decrease the incidence of high-altitude pulmonary edema in high-risk individuals.(81, 82) Experimental data suggest that manipulation of alveolar fluid clearance with β-agonists can accelerate the resolution of alveolar edema and improve survival in ARDS patients. The ARDS-Network is conducting a multicenter, randomized, controlled trial for the efficacy and safety of β-agonist therapy in ALI/ARDS patients. The goal is to determine if a sustained infusion of intravenous salbutamol would accelerate the resolution of alveolar edema in adult patients with ALI/ARDS.

SUMMARY

ARDS is the advanced manifestation of pulmonary homeostatic dysfunction, caused by local or systemic processes. While supportive therapy with mechanical ventilation remains the mainstay of care, high levels of ventilatory support are in and of themselves injurious to the remaining lung parenchyma. Multiple strategies have been described to effect pulmonary support while the underlying process resolves. The overall mortality attributed to ARDS has declined significantly, though it remains unclear to what this improvement can be ascribed. A multimodal approach to patient management that utilizes ventilator strategies, mechanical factors, and pharmacologic support is likely the best concept.

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Evidence-Based Recommendations for Mechanical Ventilation of Sepsis-Induced ALI/ ARDS*

Recommendations and Guidelines	Level of Evidence
Ventilator Settings:	
[1] Clinicians should target a tidal volume of 6mL/kg (predicted body weight) in patients with ALI/ARDS	1B
[2] Plateau pressures should be measured in patients with ALI/ARDS and the initial upper limit goal for plateau pressures in a passively inflated patient should be ≤ 30 cm H_2O. Chest wall compliance should be considered in the assessment of plateau pressure	1C
[3] Permissive hypercapnia (allowing $PaCO_2$ to increase above its premorbid baseline) is allowed in patients with ALI/ARDS if needed to minimize plateau pressures and tidal volumes	1C
[4] PEEP should be set so as to avoid extensive lung collapse at end-expiration	1C
Fluid Management:	
[1] Routine use of the pulmonary artery catheter for patients with ALI/ARDS is not recommended	1A
[2] A conservative fluid strategy should be adopted during the management of patients with established ALI/ARDS unless they are in active shock requiring fluid resuscitation	1C
Sedation/Ventilator Weaning Protocols:	
[1] Ventilator weaning protocols should be in place with the appropriate screening criteria	1A
[2] Adopt sedation protocols with a sedation goal when sedation of critically ill mechanically ventilated patients with sepsis is required	1B
[3] Intermittent bolus sedation or continuous infusion sedation to predetermined end points (e.g., sedation scales) with daily interruption/lightening of continuous infusion sedation with awakening and retitration if necessary for sedation administration to septic mechanically ventilated patients	1B

*Source: Surviving Sepsis Campaign: International Guidelines for Management of Severe Sepsis and Septic Shock: 2008. Crit Care Med 2008; 36(1): 296–327.

27 Weaning and liberation from mechanical ventilation

Walter Cholewczynski and Michael Ivy

A 50-year-old male is in the intensive care unit (ICU) on a ventilator recovering from a T8 corpectomy and reconstruction using anterior (thoracotomy) and posterior approach. His course was complicated by ventilator-associated pneumonia with Klebsiella and pneumococcus. It is postoperative day 10 and the patient is afebrile with minimal secretions.

A large part of the time and effort expended in the care of critically ill and injured patients involves respiratory failure and ventilator management. Initially, ventilator management strategies will be directed toward supporting the patient through a period of respiratory failure. Once the cause of the respiratory failure is resolving, the strategy changes to the process of discontinuing mechanical ventilation. Over the past 20 years, clinical researchers have worked on this question of how to successfully remove patients from mechanical ventilation safely with a low rate of extubation failure.

The patients' clinical course will direct the management by observing that the cause for mechanical ventilation is resolving, whether it was for primary respiratory failure resulting from pneumonia or chest injury or as part of general support for hemorrhagic or septic shock.

The spontaneous breathing trial (SBT) approach is currently the best method for assessing the appropriateness for extubation.(1, 2) Trials have been done using the T-tube method as well as breathing trials using low levels of pressure support (PS), ranging from 0 to 10 cm H_2O, and positive-end expiratory pressure (PEEP), also known as continuous positive airway pressure (CPAP), ranging from 0 to 8 cm H_2O.(3, 4) The T-tube method is a true test of unassisted spontaneous breathing; however, low levels of assisted ventilation using PS and PEEP are also commonly referred to as SBTs.

In 1994 Brochard et al. (1) compared T-tube trials, PS weaning, and intermittent mandatory ventilation (IMV) weaning. IMV weaning was the least successful. A year later Esteban et al. (2) published a comparison of IMV weaning, PS weaning, and once- and twice-daily T-tube trials (some patients underwent CPAP trials). Again, IMV was the least successful. In their trial, T-tube weaning was a faster method of extubation; however, there was no difference between the once- and twice-daily approaches.

Drs Tobin and Jubran (5) recommend a two-step approach to weaning: (1) a screening approach to assess the readiness to proceed with (2) the SBT. The readiness assessment consists of reviewing the degree of respiratory support being provided, the patient's hemodynamic status, and the patient's neurologic status.

The respiratory failure should be resolving with FIO_2 0.4–0.5, rate < 35, PEEP $\leq$ 8 cm H_2O, and PaO_2/FIO_2 > 200. Hemodynamic stability should also be in resolution with normalization of heart rate and blood pressure. Vasopressors should be weaned off or at low dose (in the case of dopamine or dobutamine). pH and lactate should be normalized. Neurologically, the patient should be aware enough to maintain an open airway. Sedatives and analgesics should be minimized either by a "sedation vacation" or by the implementation of closely monitored sedation protocols that allow patients to be alert and comfortable. Neurologic injury should be such that successful maintenance of extubation with a safe airway would be likely.

Ely et al. (6) used the following five criteria for their screen for readiness to proceed with an SBT: (1) f/Vt < 105; (2) PaO_2/FIO_2 > 200; (3) PEEP $\leq$ 5 cm H_2O; (4) adequate cough during suctioning; (5) no infusions of vasopressors or sedatives (low rate of dopamine was acceptable). Yang and Tobin (7) described f/Vt as a test to be used to prior to an SBT. f/Vt should be measured after removing the patient from assisted ventilation (no PS, no PEEP), and it can be measured within the first few minutes of unassisted ventilation. The threshold value is typically < 100.

Passing the readiness screen should lead to an SBT. The initial method of unassisted, or spontaneous, breathing trial was the T-tube trial which is still commonly used.(8) The early reports states that the patients were placed on a T-tube for 2 h and observed. In 1999, Esteban et al. (9) compared 120-minutes T-tube trials to 30-minutes T-tube trials. All patients who failed the trial did so within 30 min. SBTs using low levels of PS and/or PEEP are also widely utilized.(3, 4) Common approaches are to provide PS 5–8 cm H_2O (higher PS for endotracheal tubes < 7 mm), PEEP 5 cm H_2O, or PS plus PEEP (5 H_2O and 5 H_2O is common). The perceived advantage of using the ventilator for an SBT includes the ease of changing the settings; measuring parameters such as rate and Vt; and not having to set up a separate circuit for the T-tube. A disadvantage is not knowing how much excess support is being provided. Strauss et al. (10) conducted an elegant experiment to determine the contribution to work of breathing of the endotracheal tube compared to the natural airway in the immediate postextubation setting. They found that that the work of breathing during the T-tube trial and after extubation was identical. PS assistance is not needed to compensate for the tube (all patients had endotracheal tubes 7 mm and larger). Further, they posited that PS would only be needed for the resistance and dead space of the ventilator circuitry.

The SBT is a test to determine whether the individual patient is ready to be extubated. Patients who pass the test breathe comfortably for the set time (usually 30–120 min). Failure is recognized by (1) tachypnea, (2) increased accessory muscle use, (3) diaphoresis, (4) facial signs of distress, (5) O_2 desaturation, (6) tachycardia, (7) arrhythmias, and (8) change in blood pressure .(5)

Patients who pass an SBT should proceed to extubation. It will be the clinician's responsibility to determine on a case-by-case basis whether the data obtained from the readiness screen

and the SBT warrant extubation. Many studies report a 10–20% reintubation rate. Patients who fail the SBT should be returned to a supportive mode of ventilation, such as the assist-control for 24 h.(11)

Several studies have compared a weaning protocol to "usual care." In the early studies, improvement was documented by managing patients by a daily SBT.(6, 12–14) Many patients still were not extubated due to clinician judgment, hesitation, and being unfamiliar with how to utilize the data. Later studies did not reveal much improvement in the groups managed by the weaning protocol.(15, 16) Study design and clinician education over time may have changed "usual care" to come more in line with current concepts in weaning. A recently published article by Robertson et al. (4) evaluated an SBT protocol where an educational effect appears to have had an impact over time with an improvement in the time to extubation with no change in the reintubation rate.

Patients should be assessed for the presence of an air leak or cuff leak around the endotracheal tube.(17, 18) The lack of a cuff leak should alert the clinician to the possibility of laryngeal edema and of developing postextubation stridor, which can lead to extubation failure and can increase the risk of a difficult intubation. A patient with a leak $\leq$ 110 ml on ventilatory support is more likely to develop stridor or laryngeal edema than those with leaks > 110 ml. A multicenter randomized trial conducted in France found that pretreatment with steroids could reduce the incidence of postextubation laryngeal edema and the need for reintubation.(19)

Keeping the patient in an upright posture should minimize aspiration risk and subsequent pneumonia (20, 21) and will enhance performance on the SBT.

The patient passes an SBT and is extubated; however, 48 h later he is reintubated for increased work of breathing. Workup reveals a pulmonary embolus that is treated. The patient is subsequently diagnosed with a new ventilator-associated pneumonia. It is now postoperative day 21 and the patient continues to fail SBTs.

When a patient continues to fail SBTs, a diligent search for the causes of respiratory failure should be undertaken.(22) Causes of continued need for mechanical ventilation include impairments in respiratory mechanics, metabolism, gas exchange, cardiovascular stability, as well as psychological issues.

Tracheostomy is an often used modality in patients who fail SBTs. It is also used when clinical judgment presumes that extubation is unlikely in the near term. Benefits of tracheostomy include improved comfort (23), more effective airway suctioning, decreased airway resistance (24), enhanced mobility, possibility for speech and oral feeding, and improved security of the airway.(22) Lesnik et al. (25) compared day 6 tracheostomy with those done on day 21 in a group of blunt trauma patients and found that the total ventilator days were fewer with early tracheostomy; whereas, Sugarman et al. (26) found no benefit to early tracheostomy.

Freeman et al. (27) presented a tracheostomy protocol based on failure of preliminary weaning assessments and SBTs. Adherence to their protocol was optional with some patients remaining intubated until extubation and others undergoing tracheostomy after passing SBTs; however, development and implementation of a tracheostomy protocol based on objective criteria of persistent failure of SBT have the prospect of improving the decision making and timing of tracheostomy.

Complications of tracheostomy are primarily related to the procedure itself: bleeding (with atelectasis from clots in the airways), hypoxia, arrhythmia, esophageal injury, pneumothorax, loss of the airway, and death. Long-term complications include tracheal stenosis, tracheostomy site infections, and erosion into vascular structures (tracheoinnominate fistula). Tracheal stenosis rates are about the same as subglottic stenosis rates from prolonged translaryngeal intubation.(28)

Tracheostomy can be performed in the operating room (OR) or in the ICU. Procedures performed in the ICU avoid costs associated with the OR.(29, 30) Tracheostomy can be performed in an open approach or by the percutaneous route. Percutaneous methods vary by degree of neck dissection and whether or not bronchoscopy is utilized.(31) In addition to surgeons, pulmonologists and anesthesiologists have learned to perform percutaneous tracheostomy, particularly in ICU settings.

SBTs	Ref	ACCP evidence grade
Daily T-piece trial superior to IMV or PS wean	2	1A
Daily SBT (PS 5, PEEP 5) superior to usual care	4	1C
Daily SBT (T-piece or CPAP 5) superior to usual care	6	1A
Once-daily SBT equal to multiple-daily SBT	2	1A
T-piece equal to PS 7	3	1A
30-minutes SBT equal to 120 minutes	9	1A
$f/Vt < 100$ predicts successful SBT	7	1B
Weaning Protocols		
Implementation of weaning protocol superior to usual care	12	1C
Weaning protocol by RCP/RN superior to usual care by MD	13	1B
Ventilator management protocol superior to usual care	14	1B
Weaning protocol equal to usual care	16	1A
Stridor / Laryngeal edema		
Cuff leak < 110 cc predicts stridor	17,18	1C
Pretreatment with methylprednisolone decreases laryngeal edema	19	1A

Tracheostomy	Ref	ACCP grade
Tracheostomy decreases work of breathing		
Early tracheostomy (< 4 days) decreases vent days and VAP	24 25	1C 1C
No benefit to early tracheostomy (3–5 days)	26	1B
Tracheostomy protocol can be incorporated into weaning protocol	27	1C

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28 Deep vein thrombosis and pulmonary embolism

Wesley D McMillian and Frederick B Rogers

A 50-year-old obese motorcyclist is admitted to the emergency department hypotensive and is emergently taken to the operating room for damage control surgery for a Grade 4 liver laceration and expected large volume resuscitation. In addition to the liver laceration, he is found to have the following injuries: bilateral femur fractures and pulmonary contusions, pelvic fracture, and a small intracerebral hematoma. Immediately postop, the patient is transferred to the surgical intensive care unit (SICU) for stabilization, optimization of his mechanical ventilation requirements, and aggressive correction of his metabolic disturbances in preparation for definitive fascial closure and fixation of his pelvis and femur fractures. Pharmacologic deep vein thrombosis prophylaxis is withheld secondary to the small intracerebral hematoma (ICH) documented on head computed tomography (CT). The patient is started on mechanical sequential compression devices (SCDs) for primary prevention of venous thromboembolism (VTE). On post-operative day (POD) 10, the patient develops acute respiratory distress manifested by hypoxemia, tachypnea, and hemoptysis. A pulmonary embolus is diagnosed on spiral CT and subsequently a deep vein thrombus is discovered in the patient's proximal left femoral vein by duplex ultrasound. The patient is initiated on a weight-based enoxaparin regimen. After several days of combination anticoagulant therapy, the patient is successfully bridged to warfarin treatment. On POD 20, the patient was on trach collar for 24 h and is subsequently transferred to a ward bed. The patient is discharged to a rehabilitation facility 5 days later with a plan to continue warfarin for the next 3 months.

VENOUS THROMBOEMBOLISM: GENERAL OVERVIEW

What Are the Risk Factors for Venous Thromboembolism?

Several studies have assessed the independent risk factors for the development of venous thromboembolism (VTE) (deep vein thrombosis and pulmonary embolism) in trauma patients (Table 28.1).(1–5) These risk factors are generally cumulative, and patients in this population usually have more than one risk factor for the development of VTE.

What Is the Incidence of Deep Vein Thromboses and Pulmonary Embolisms in Trauma Patients?

The incidence of deep vein thromboses (DVT) range from 10 to 20%, and pulmonary embolisms (PE) have been shown to occur in approximately 2–3% of this population. The subsequent

Table 28.1 Risk Factors for Venous Thromboembolism(8).

Risk Factor	Odds ratio (95% CI)
Ventilator Days > 3	10.62 (9.32–12.11)
Venous Injury	7.93 (5.83–10.78)
Major Surgical Procedure	4.32 (3.91–4.77)
Spinal Cord Injury with Paralysis	3.39 (2.41–4.77)
Lower Extremity Fracture	3.16 (2.85–3.51)
Pelvic Fracture	2.93 (2.01–4.27)
Head Injury (AIS ≥ 3)	2.59 (2.31–2.90)
Age ≥ 40	2.29 (2.07–2.55)
Shock on Admission (BP < 90 mmHg)	1.95 (1.62–2.34)

AIS: Abbreviated Injury Scale; BP: blood pressure
Source: Ref(8) – (need permission)

mortality rate of PE has been found to range from 0.2 to 5%. (1, 6–10) However, in patients not receiving prophylaxis, the incidence may be up to 60%. The diagnosis of DVT in high-risk patients is more frequent in venography studies (50–60%) compared to ultrasound studies (8–12%). Inferring the variability in rates of DVT/PE is more likely related to the diagnostic technique used rather than a true variation in the incidence of VTE.

What Is the Timeline for Development of Deep Vein Thromboses/Pulmonary Embolisms?

Trauma patients are at high risk for VTE immediately after injury as described by the elements of Virchow's Triad (11): vascular damage, venous stasis, and hypercoagulability. Hypercoagulability is a well-known phenomenon after trauma. Seyfer and colleagues (12) demonstrated that antithrombin III (AT III) levels fall precipitously within hours after severe trauma, indicating a hypercoagulable state. However, venous intimal injury appears to be the major culprit behind DVT formation. The body's natural response to venous trauma is to mitigate bleeding from torn blood vessels. Exposed proteins on the damaged endothelium initiate platelet activation and adhesion and ultimately lead to thrombin generation and subsequent thrombosis (Figure 28.1).(13) Significant proximal DVTs and embolized clot can occur as early as 24 h from the initial insult. It has been noted that most PEs (70%) occur in the first week after injury. (1, 9) However, PE can develop several weeks into a patient's hospital course or even months after discharge.(14, 15) Lamb et al. (16) followed 287 spinal cord injury patients for a mean of 13.7 years. Thirty-three (83%) of all VTE events occurred within 6 months of injury. Of note, the authors found that after these 6 months, the incidence of VTE returned to that of the general population (0.18%).

Surface XII
Prekallikrein
HIgh-Molecular-Weight Kininogen

Tissue Factor
Ca2$^+$

XI → XIa   VIIa ← VII

IX → IXa

VIII → VIIIa   Ca2$^+$

FONDAPARINUX

Antithrombin III ┈┈┈→ X → Xa   **LMWH**

XIII

V → Va

Ca2$^+$

HAPARIN

II → IIa →
(Prothrombin) (Thrombin)

XIIIa

DTI   Ca2$^+$

Fibrinogen → Fibrin → Stabilized Fibrin

Intrinsic Pathway   **Estrinsic Pathway**
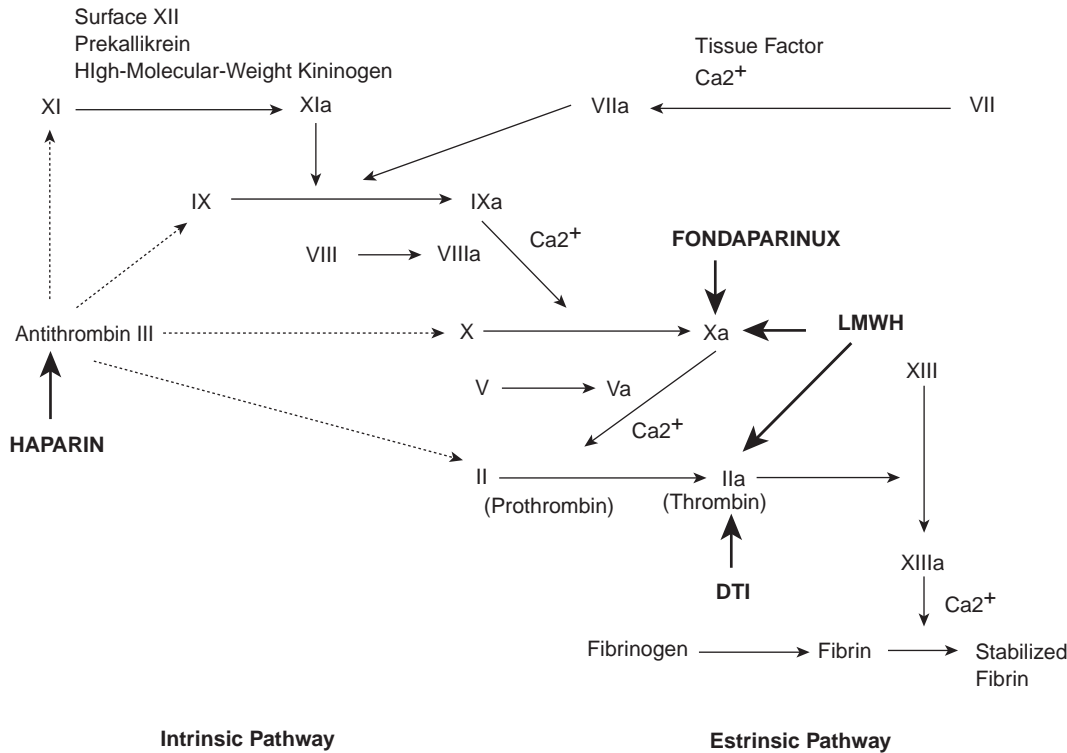
Figure 28.1 Coagulation cascade and sites of action of various anticoagulants. LMWH = Low molecular weight heparin; DTI = Direct Thrombin Inhibitor.

Need permission from reference 13.

How Does One Prevent Deep Vein Thromboses/Pulmonary Embolisms in Trauma Patients?

The recognition that trauma patients are in the highest risk category for development of VTE is of utmost importance, and as such, preventive strategies should be implemented as soon as feasible (Figure 28.2). There are three generally accepted methods for prevention of DVT and PE: (1) attachment of intermittent SCDs to the patient's lower extremities, (2) pharmacological prophylaxis, and (3) inferior vena cava filter (IVCF) placement.

What Is the Role of Mechanical Compression Devices?

SCDs compress the vascular bed in the lower extremities to expel blood and increase blood flow. They effectively substitute for the inactive muscle pumps of the calves in nonambulatory patients. Peak femoral venous blood flow may increase up to 240% during the SCD compression cycle.(17) A second, albeit less important, mechanism of VTE prevention with SCDs is direct mechanical activation of the fibrinolytic system. Venous compression results in the release of plasminogen activators, found in high concentrations throughout the vein wall, leading to an increase in local fibrinolytic activity.(18–20) Yet the effect of SCDs on the fibrinolytic system is short-lived. Jacobs et al. (19) demonstrated that plasminogen activator plasma levels return to baseline within minutes of SCD removal. Knudson et al. (2) completed a study to assess the utility of SCDs compared to placebo in multi-injured patients and found that SCDs decreased VTE in only the subset of head-injured patients. In a randomized trial of venous foot pumps versus SCDs, the rate of DVT was three times higher (6.5 vs 21%, $p = 0.009$) in the venous foot pump cohort.(21)

This study showed a lack of efficacy of the venous foot pump in multisystem trauma patients. SCDs were reviewed in a recent meta-analysis and found to confer no significant benefit over placebo for DVT prevention (OR, 0.77; 95% CI, 0.27–2.24). (22) The Chest Guidelines for prevention of VTE (23) recommend the use SCDs in trauma patients only when they have active contraindications to pharmacological prophylaxis, such as those with high risk for bleeding. SCD prophylaxis is still widely used in the SICU because it does not increase the risk of hemorrhage. Unfortunately, many patients cannot tolerate the use of SCDs because of lower extremity fractures or injures. Shackford et al. (5) found that SCDs could not be placed 35% of the time because of casts, traction, or external fixators, thus limiting this modality for VTE prophylaxis to approximately 65% of the trauma population. However, if SCDs are used for VTE prophylaxis, they should remain on during the patient's entire hospital course to reap the benefits of the local antithrombotic effects.

What Are the Roles of Unfractionated Heparin, Low-Molecular-Weight Heparins, and Fondaparinux?

Several studies have sought to determine the efficacy of heparin, low-molecular-weight heparin (LMWH) and fondaparinux for prevention of VTE in trauma patients. Pharmacologically, these agents bind to and enhance the activity of AT III. Heparin activity through AT III promotes inactivation of factors IXa, Xa, XIIa, and IIa, whereas LMWHs inhibit factors Xa and IIa.(24) The relative anti-Xa to anti-IIa activity of heparin (1:1), dalteparin (2.7:1), and enoxaparin (3.8:1) is predominantly a function of the length of the polysaccharide moiety.(25) The pentasaccharide molecule, fondaparinux, is considered an indirect factor Xa inhibitor because it

Risk for VTE

High   Low

Risk for
Bleeding   SCDs until Ambulatory
                                      (able to walk 100'
                                      unassisted)

Yes   No

Anticipated   Anticipated
Immobility   Immobility

> 6 weeks   < 6 weeks

IVCF   SCDs   SCDs with
                            Enoxaparin
                            30 mg SQ q12h

Permanent   Removable IVCF
IVCF   (non-lifelong disability)
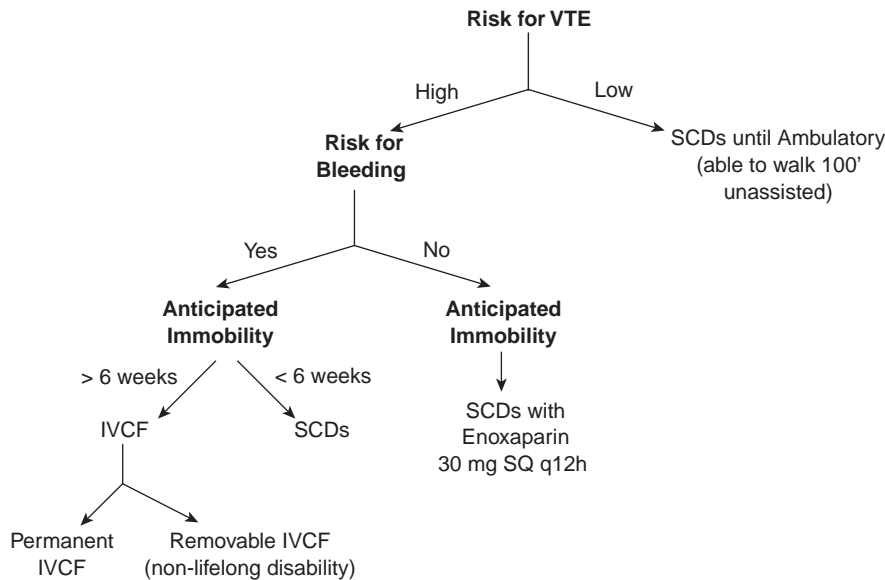
Figure 28.2 Algorithm for venous thromboembolism prophylaxis in the trauma patient. VTE = venous thromboembolism; IVCF = inferior vena cava filter; SCDs = sequential compression devises; SQ = subcutaneous.

contains the minimum number of molecules necessary for AT III activation and does not facilitate binding with the other procoagulant factors.(26) However, the active half-life of fondaparinux is substantially longer than heparin and LMWHs, which may limit its clinical application in trauma patients where the potential for bleeding is present.

Heparin

Low-dose unfractionated heparin (UFH) has been reviewed for use in VTE prophylaxis and was found to be ineffective in trauma patients.(27, 28) In a meta-analysis of randomized controlled trials of VTE prophylaxis in trauma patients, Velmahos et al. (22) found that subcutaneous (SQ) heparin conferred no benefit over no prophylaxis in reducing the incidence of DVT (OR 0.965; 95% CI 0.353–2.636).

Low-Molecular-Weight Heparins

Enoxaparin

LMWH agents have become the preferred pharmacological prophylaxis for VTE in patients with major trauma. Two prospective randomized studies have assessed the use of enoxaparin in multitrauma patients. Knudson et al. (3) randomized 487 consecutive high-risk trauma patients to LMWH, SCDs, or the arteriovenous foot pump for DVT prophylaxis. Using serial ultrasounds, DVTs were diagnosed in 0.8, 2.5, and 5.7% of these patients, respectively. Geerts et al. (29) randomized 265 patients to receive heparin 5000 units SQ twice daily (BID) or enoxaparin 30 mg SQ BID. The patients were followed with serial venograms. The proximal DVT rate was twofold higher in the heparin cohort compared to enoxaparin-treated patients (14.7 vs. 6.2%, $p = 0.014$). There were no significant differences in major bleeding complications between the two groups. In another study, Rutherford and colleagues (30) found that a regimen of daily SQ injections of enoxaparin 40 mg in trauma patients was associated with underdosing for VTE prevention. Five patients (29%) had documented undetectable

anti-factor Xa (anti-Xa) trough levels, and one patient developed a femoral DVT with the once-daily regimen. The safety and efficacy of enoxaparin depends on the clinical state of the patient. Renal failure, obesity, vasopressor use, and changes in volume of distribution (>10 kg change in body weight following admission) may predispose patients to altered pharmacokinetics.(31) These populations may benefit from anti-Xa level monitoring. However, specific anti-Xa levels have not been correlated with VTE prevention or bleeding aversion. Levine and colleagues (32) reported an incidence of thrombosis of 6.3% when the anti-Xa level was > 0.1 IU/mL and 18.8% when the level was ≤ 0.05 IU/mL. The results of this study have been used to define the prophylactic anti-Xa level for VTE prevention of 0.1–0.3 IU/mL. In clinical practice, the anti-Xa level is usually obtained 4 h after the third enoxaparin dose administration.(33–35) Haas et al. (31) conducted a pharmacokinetic study of enoxaparin 30 mg SQ BID in multitrauma patients and found that only 9.5% of the treated patients were within the goal anti-Xa level (> 0.1 IU/mL) at the end of the 12 h dosing interval. These results indicate that a standardized dose of enoxaparin may not be efficacious for prevention of VTE in all multitrauma patients.

Dalteparin

Clinical experience with dalteparin is increasing in the trauma population. A single-center open-label evaluation of 743 high-risk trauma patients who received dalteparin 5,000 IU SQ daily reported rates of proximal DVT and nonfatal PE of 3.9 and 0.8%, respectively.(36) Preliminary data in spinal cord injury suggest that dalteparin 5,000 IU SQ daily and enoxaparin 30 mg SQ BID provide similar protection from DVT and have comparable bleeding risk.(37) Slavik and colleagues (38) completed a retrospective analysis of enoxaparin 30 mg SQ BID (Phase 1) compared to dalteparin 5,000 units SQ daily (Phase 2) in high-risk trauma patients. Although this study was inadequately powered to show a statistically significant difference, it suggests that enoxaparin may be more efficacious in preventing clinically

symptomatic VTE (1.6 vs. 9.7%, $p = 0.103$). This was evident in light of a significantly larger number of held doses in the enoxaparin group (46 vs. 25%, $p = 0.017$). The regimens appear to have equivalent safety as shown by the similarities in major bleeding rates (6.4 vs. 6.9%, $p = NS$) and mortality (4.8 vs. 6.9%, $p = 0.865$). Given these data, it is clear that extrapolating therapeutic equivalence among LMWHs would not be appropriate due to a lack of studies assessing efficacy by following anti-Xa levels, administration times, or diagnostic methods of DVT/PE.

Fondaparinux

It is important to note that fondaparinux has never been evaluated for VTE prophylaxis in multisystem trauma patients. Most clinical data supporting fondaparinux use in VTE prophylaxis has been conducted in the high-risk orthopedic patient population. Agnelli et al. (39) randomized 2,048 patients to postoperative fondaparinux or perioperative dalteparin in high-risk abdominal surgery patients. The reported VTE rates were 4.6% with fondaparinux compared to 6.1% with dalteparin. No differences were found in rates of fatal PE (0.2% in both groups) or major bleeding (3.4% fondaparinux vs. 2.4% dalteparin). The disadvantages of using fondaparinux in the trauma population are the lack of efficacy of protamine as a reversal agent in the case of major bleeding and the long effective half-life (18 h).(40)

What Are the Contraindications to Pharmacological Prophylaxis?

Contraindications to the administration of LMWH for VTE prophylaxis include ongoing and uncontrollable bleeding, incomplete spinal cord injury associated with suspected or proven perispinal hematoma, uncorrected coagulopathy, or the presence of intracranial bleeding.(23) Prophylaxis in this patient population is limited to graduated compression stockings, IVCF insertion, or SCDs, unless there are active contraindications to this modality such as tibia or fibula fracture.

> The case patient has a small ICH diagnosed on head CT and therefore pharmacological VTE prophylaxis is contraindicated. Subsequently, the patient has SCDs placed on his lower extremities for primary VTE prevention.

Is There a Role for Prophylactic Inferior Vena Cava Filter Insertion?

Over the past decade, some trauma surgeons have been placing IVCF in patients at high risk for PE, despite the absence of a documented DVT or PE. Technologic advances have enabled filters to be placed percutaneously through very small carrier sheaths and via previously inaccessible sites, such as the antecubital vein.

Unfortunately, decisions about the effectiveness of IVCF in trauma patients are primarily based on their overall performance in case series, as there are not yet any randomized trials. A number of studies have looked at the use of IVCF to prevent PE in trauma patients (Table 28.2).(41–64) Many of these studies have noted a decrease in PE rate compared to a concurrent population of non-IVCF patients or historical controls. Fullen (41) reported on

a prospective randomized study of IVCF in hip fracture patients in which there was a statistically significant decrease in PE in the IVCF group (1 vs. 12 in the control group). Patients were well matched for age, comorbidities, fracture type, and time to fixation. However, this study is over 30 years old and our ability to prevent DVT and PE has changed significantly during this period. Furthermore, this study was done in patients with isolated hip fractures; it is unknown whether these results could be translated to the multisystem trauma patient. It is important to note that none of these studies reported routine screening for PE.

In 2002, the Eastern Association for the Surgery of Trauma published their Practice Management Guidelines for the prevention of VTE in trauma patients (65), analyzing the available medical literature regarding prophylactic IVCF insertion in high-risk trauma patients. Although there were no large, well-designed prospective randomized trials (Class I data) to support prophylactic IVCF insertion in high-risk injured patients, there was a reasonable amount of retrospective and case series data (Class II and Class III data) to support the recommendation for *consideration* of IVCF insertion in high-risk patients who cannot receive prophylactic doses of anticoagulation. Contraindications for anticoagulation include brain hemorrhage, solid organ injuries, or any injury where the risk of further hemorrhage is too great for even prophylactic doses of anticoagulation. The high-risk criteria include head injury (Glasgow coma score < 8), spinal cord injury, head injury plus long bone fractures, severe pelvic fracture plus long bone fracture, and multiple long bone fractures. Importantly, once the contraindications to pharmacologic prophylaxis subside, the presence of an IVCF should not be considered DVT prophylaxis (or treatment) and chemical VTE prevention (or treatment) should be initiated.

Complications reported in prophylactic IVCF studies were sporadic and ranged anywhere from 0 to 36%, depending on types of complications reported. Types of complications reported included filter misplacement or tilt, groin hematoma, arterial venous fistula, filter migration, insertion site thrombosis, inferior vena cava thrombosis, and post-phlebitic changes. The longest follow-up in any one study was 42 months. Of note, in the 24 studies of prophylactic filter placement, there were three patients who died from PE in 2,142 prophylactic filter placements.(66) Insertion-site DVT and caval thrombosis are significant concerns regarding the use of IVCF, especially in the young injured patient who has a relatively brief duration of PE risk (several weeks).(67) The contrary belief is that acute caval thrombosis is likely to occur because of the actual trapping of an otherwise large PE; thus, it is a lifesaving event. Notably, the caval thrombosis incidence reported by Rogers parallels the PE risk in these high-risk patients.

Much of the concern regarding the long-term risks of prophylactic VCF in trauma patients stems from subjecting patients with a relatively brief risk period to the possible long-term complications of a permanent device. This may be addressed by the development of "optional" IVCF. These devices may be left in permanently or be removed when the high-risk period is over.

In summary, although there is mostly Class III data that show efficacy of filters, there is no Class I study that shows effectiveness of prophylactic IVCF in preventing PE in the multisystem trauma patient. Despite the lack of ironclad evidence that prophylactic IVCFs

Table 28.2 Studies of Prophylactic IVCF in Trauma Patients.

Author	Year	Number of Patients	Study Type	Type of Filter	PE with Filter/*PE with Control**	Complications
Fullen(41)	1973	100	Prospective Randomized Controlled Trial	Stainless Steel Greenfield (SSGF)	1/41 and *1/59†*	NA
Thomas(59)	1988	22	Case Series	SSGF	0/NA	36%
Rohrer(55)	1990	66	Case Series	SSGF	3/NA	4.6%
Webb(56)	1992	24	Case Series	SSGF	0 and *3/27*	17%
Wilson(61)	1994	15	Case Series	Titanium Greenfield (TGF)	0 and *7/111*	0
Zolfaghari(64)	1995	45	Case Series	Vena Tech (VT)	0/NA	0
Patton(50)	1996	110	Case Series	TGF	0/NA	7%
Nunn(49)	1997	55	Case Series	TGF	0/NA	8.2%
Rogers(54)	1998	132	Case Series	TGFG, SSGF, VT, Birds Nest (BN	3/NA 1 Fatal	12%
Langan(46)	1999	187	Case Series	TGF, SSGF	1/NA	12.8% 1 Nonfatal PE
Hughes(44)	1999	2	Case Series	Temporary Filter	0/NA	0
Wojcik(63)	2000	191	Case Series	TGF, BN, Simon-Nitond	0/NA	10.4%
Sekharan(58)	2001	108	Case Series	TGF, SSGF	0/NA	8%
Rosenthal(57)	2004	94	Case Series	OpTease	NA	5.3%
Morris(48)	2004	55	Case Series	TGF	0/NA	0.4%
Leach(47)	1994	205	Case Series with Historical Controls	TGF	0 and *4/10.948* All Fatal	1.5%
Rosenthal(56)	1994	129	Case Series with Historical Controls	SSGF	0 and *15/161*	NA
Winchell(62)	1994	29	Case Series with Historical Controls	NA	0 and *36/9.721*	NA
Khansarinia(45)	1995	108	Case Series with Historical Controls	SSGF	0 and *13/216*	10.85%
Rogers(53)	1995	63	Case Series with Historical Controls	TGF	1 and *25/2 525*	30%
Rodriguez(51)	1996	40	Case Series with Historical Controls	TGF	1 and *14/80†*	10%
Gosin(42)	1997	99	Case Series with Historical Controls Concurrent	TGF	1.6%/4.8%	NA
Headrick(43)	1997	228	Case Series with Historical Controls	NA	0 and *6/234*	17%
Rogers(52)	1997	35	Case Series with Historical Controls	TGF, BN	1/35 and *11/1.150*	7.4%

*Number of PEs in Filter Group and number of PEs in Control Group
†Statistically significant

work to prevent PE in the trauma patient, the number that are being placed has increased almost exponentially in the past 15 years. A query to the National Trauma Data Bank, which receives data on trauma patients from 236 trauma centers in 36 states, revealed that of patients entered into the data bank in 1994, 47 (0.3%) received a prophylactic IVCF.(66) The number of IVCFs placed has also increased over the ensuing years. In 2002, there were 1,054 (1.2%) placed, an increase of 340%. A recent survey shows that IVCFs are used as routine prophylaxis in 29% of major trauma centers in the United States.(68) The lack of definitive data on prophylactic IVCF effectiveness in trauma patients, coupled with their rapidly increasing use, strengthens the argument that a randomized prospective double-blind (Class I) study must be done to assess the effectiveness of prophylactic IVCF in trauma patients. While many efficacy studies show that filters can be placed with a low insertion-related morbidity, we need an effectiveness study showing that IVCF can

prevent death from PE in the trauma patient. Undoubtedly, such a study will require a number of participating institutions (since PE has an overall low incidence) and will be costly to undertake. Nonetheless, the debate of IVCFs as prophylaxis for PE will not be resolved until such a study is undertaken.

> On hospital day 7, the patient develops hypoxia and is noted to have significant right leg swelling and tenderness.

How Does One Diagnose Deep Vein Thromboses/Pulmonary Embolisms?

DVT

The clinical signs and symptoms of DVT include leg pain, warmth, redness, dilation of superficial veins, palpable cord, or leg swelling. Many DVT (up to 79%) have an insidious onset and only manifest when embolization occurs to the pulmonary vasculature.(69) Physical examination, venography, ultrasound, impedance plethysmography, and magnetic resonance venography (MRV) are modalities that can by used to detect DVTs.

Ultrasound

Real-time B-mode ultrasonography allows bedside visualization of the leg veins by high-frequency sound waves that are reflected off of soft tissues. The frequencies are received by the ultrasound transducer and are displayed on a visual monitor. Vein incompressibility detected in this mode is considered diagnostic for DVT.(70) Doppler ultrasonography evaluates blood flow through veins, through reflections of sound waves off of red blood cells. The Doppler effect (frequency) is proportional to the velocity of blood flow. The accuracy of Doppler ultrasonography is highly dependent on the skill of the sonographer. Overall, the sensitivity and specificity of Doppler ultrasound to detect proximal DVT in symptomatic patients were 85 and 88%, respectively. (71) Duplex ultrasonography combines real-time B-mode ultrasound with Doppler ultrasonography providing an image of the venous circulation while also providing information about blood flow.(72) As with Doppler ultrasound, duplex ultrasound quality is user dependent. In a review of asymptomatic high-risk patients by Agnelli and colleagues (73), duplex ultrasonography did not appear to be accurate as a screening method for DVT. Furthermore, in four level I studies, the sensitivity and specificity of duplex were found to be 61 and 97%, respectively. The ability of duplex or Doppler ultrasound to detect clinically important DVT has come into question because of the frequency of fatal PE in the setting of a negative ultrasound screen.(74, 75) Also, the use of serial Doppler ultrasound examinations has not been found to be cost-effective in high-risk patients receiving routine VTE prophylaxis.(76)

Venography

Radiographic contrast studies are the most accurate and reliable methods for detection of DVT and are considered the gold standard in clinical trials.(77–79) Contrast venography allows visualization of the entire venous system of the lower extremities. Persistent intraluminal filling defects on a series of X-rays lead to diagnosis of DVT. Severely ill trauma patients are often unable to tolerate the procedure secondary to hypotension or cardiac arrhythmias associated with the contrast dye. Although contrast venography can provide a definitive diagnosis, these studies are expensive, invasive, and can promote VTE and contrast-induced nephropathy. Noninvasive techniques, such as Doppler ultrasound, are used in clinical practice for the initial evaluation of patients with suspected DVT because these modalities are less invasive and have fewer adverse events associated with their use.

MRV

MRV is very useful in areas where venograms or ultrasound may be ineffective in detecting DVTs. Montgomery and colleagues (80) studied 100 patients undergoing acetabular fracture repair and found 49 to have asymptomatic DVTs. Of note, 14 (29%) of these patients were found to have DVTs in the internal iliac veins, a location inaccessible to ultrasound and venography. Other studies (81, 82) have shown MVR to be more sensitive in DVT diagnosis. MVR is a promising new tool for diagnosis of DVT; however, the clinical usefulness in the trauma population has come under scrutiny. MVR is more expensive than other diagnostic modalities. Additionally, patients need to be transported to the MR scanner and remain unmonitored for the duration of the scan. There are compatibility issues with internal/external fixators, specifically if they are ferromagnetic, and the bore of the MR scanner may prohibit successful scans in patients with bulky external devises.

PE

Patients who have an acute PE often present with dyspnea, chest pain, hemoptysis, cough, palpitations, light-headedness, fever, wheezing, tachypnea, diaphoresis, neck vein distention, or tachycardia. However, PEs are clinically asymptomatic in up to 75% of patients.(83, 84) Ventilation–perfusion scans, angiography, and contrast-enhanced spiral CT are commonly used modalities to diagnose PE.

Spiral Computed Tomography

Contrast-enhanced spiral CT produces a volumetric two-dimensional image of the lung with a total image acquisition time of 30 s. In a review of helical CTs, Rathbun and colleagues (85) noted that the sensitivity and specificity of detecting PE were 53–100% and 81–100%, respectively. The large span of specificity could not rule out the true possibility of PE. Goodman et al. (86) prospectively followed 198 patients with an initially negative helical CT scan for PE and who also did not receive anticoagulation therapy. Pulmonary embolism was subsequently found in only two (1%) of these patients. The authors concluded that a negative helical CT scan reliably excludes clinically important PE. Schultz and colleagues (15) found a 24% incidence of asymptomatic PE by contrast-enhanced CT in a prospective study of trauma patients admitted with an injury severity score ≥ 9. The significance of this observation on morbidity or mortality end points is unknown.

D-dimer

The D-dimer assay is a relatively inexpensive test used in detection or screening for DVT or PE. D-dimer is a thrombus breakdown product that can be detected in the blood and, as such, signifies that significant clotting has occurred. Johna et al. (87) prospectively studied D-dimer levels for 14 days in 21 severely injured trauma patients. During the first 3 days after injury, the authors noted increased D-dimer levels above a threshold of 500 mg/mL, potentially below which DVT or PE could be clinically ruled out. After 3 days, the levels gradually taper toward normal values. In a study by Wahl and colleagues (88) of 23 severely injured trauma patients who developed DVT or PE, the false-negative rate of the D-dimer assay was 24% within the first 4 days after the initial insult. After 4 days, the negative predictive value rose to 100%. Owings et al. (89) reviewed 486 patients being screened with D-dimer for suspected DVT or PE. All patients with a diagnosis of DVT or PE had a positive D-dimer level. The authors concluded, in stable surgical patients, that a negative D-dimer test successfully rules out VTE and negates the need for further workup.

What Are the Current Treatment Modalities for Deep Vein Thromboses and Pulmonary Embolisms?

When acute DVT or PE is suspected or diagnosed, anticoagulation with an LMWH, fondaparinux, or a continuous infusion of UFH should commence unless contraindications to anticoagulation exist. These agents allow the endogenous fibrinolytic system to dissolve the thrombi while preventing new clot development or propagation of established thrombi. Thrombolysis with recombinant tissue plasminogen activator (t-PA) is warranted in patients with massive pulmonary embolism and associated hemodynamic compromise. However, the use of t-PA in submassive PE remains debatable and potentially dangerous in the trauma patient.

Heparin

Treatment with UHF (Table 28.3) is based on body weight and is titrated based on activated partial-thromboplastin time (aPTT) to a goal of 1.5–2.5 times control.(90) The aPTT should be monitored every 6 h (three times the approximate half-life of UFH for achieving steady state) until it is consistently in the therapeutic range. The commercial aPTT reagents vary in their response to heparin. Therefore, it is imperative for each institution to devise an in-house weight-based algorithm.(91) The risk of adverse effects secondary to UFH include recent surgery, age > 65 years, and bleeding diathesis. Heparin-associated thrombocytopenia (formerly Type I heparin-induced thrombocytopenia [HIT]) can occur in up to 20% of patients. This transient drop in platelet count generally occurs during the first few (2–4) days of therapy. However, HIT (Type II) is a relatively rare (1–3%) but a highly morbid adverse effect of UFH.(92) Bleeding complications with UFH are usually less than 2%.(93) Fortunately, heparin-associated bleeding can be reversed by administration of protamine sulfate. One milligram of protamine sulfate should be given for every 100 units of UFH up to a maximum of 50 mg.

Table 28.3 Weight-based Dosing of IV Unfractionated Heparin (90).

aPTT[+]	Dose Change units/kg/hr	Additional Action	Next aPTT[x], hours
< 1.2 x mean normal	4	Rebolus 80 units/kg	6
1.2–1.5 x mean normal	2	Rebolus 40 units/kg	6
1.5–2.3 x mean normal	0	0	6
2.3–3 x mean normal	–2	0	6
> 3 x mean normal	–3	Stop drip for 1 h	6

[+]aPTT, activated partial-thromboplastin time
Initial intravenous heparin loading dose 80 units/kg followed by 18 units/kg/hr
[x]Check aPTT every 6 h for the first 24 h and then daily thereafter, unless aPTT is out of the therapeutic range

Need permission from reference 90

LMWH

The LMWHs have many advantages over UFH, including SQ administration, lower risk of HIT, more predictable pharmacokinetic and pharmacodynamic properties, and less need for laboratory monitoring.(94) In patients diagnosed with DVT or PE, LMWHs subcutaneously administered have been shown to be safer (fewer bleeding episodes) and possibly more effective (reduced number of recurrent episodes) than continuous infusions of UFH.(95, 96) The LMWHs are cleared primarily through renal excretion and are independent of dose. Predictably, the effective half-lives of LMWHs are prolonged in patients with renal insufficiency (creatinine clearance < 30 mL/min). Anti-factor Xa activity monitoring is necessary in patients with renal insufficiency, low body weight (< 40 kg), and in the obese population (> 150 kg). Dosing for DVT treatment with or without concurrent PE is 1 mg/kg SQ BID for enoxaparin and 200 units/kg SQ daily for dalteparin.(97) However, the frequency of administration is dependent upon renal function as measured by creatinine clearance. Bleeding associated with the use of LMWHs can be partially reversed by protamine administration (60–75%). Hemorrhagic complications of LMWHs may be reversed by giving 1 mg of protamine sulfate intravenously for every 100 anti-Xa IU of LMWH given.

Fondaparinux

Similar to LMWHs, fondaparinux has improved bioavailability, SQ administration, and little to no risk of HIT when compared to UFH. In a randomized, double-blind study of 2, 192 patients by Büller et al. (98), the use of enoxaparin 1 mg/kg SQ BID was compared to the use of weight-based daily SQ dosing of fondaparinux for treatment of DVT (body weight < 50 kg: 5 mg, 50–100 kg: 7.5 mg, > 100 kg: 10 mg). Total VTE (3.9% enoxaparin vs. 4.1% fondaparinux) and fatal PE (0.5% both groups) cases were similar between groups. In a similar noninferiority study, the Matisse Investigators (99) compared weight-based SQ dosing of fondaparinux to an aPTT adjusted continuous

intravenous infusion of UFH for treatment of acute symptomatic PE. Recurrent thromboembolism occurred in 42 patients (3.8%) in the fondaparinux group compared to 56 patients (5.0%) in the UFH group. Bleeding rates were also similar (1.3% fondaparinux vs 1.1% UFH). These results indicate that fondaparinux is as safe and effective as UFH for treatment of acute symptomatic PE.

Direct Thrombin Inhibitors

The direct thrombin inhibitors, argatroban and lepirudin, are FDA approved to treat thromboses associated with HIT. These agents are capable of inhibiting clot bound and free-circulating thrombin, a potential benefit over the LMWHs.(100) Lepirudin is cleared through renal mechanisms and must be dose reduced in patients with renal insufficiency, whereas argatroban is hepatically metabolized and dosing must be altered in patients with hepatic insufficiency. Continuous intravenous infusions are required for this class because of their relatively short elimination half-lives. Lepirudin and argatroban are titrated to an aPTT target range of 1.5–3 times the normal control. After the platelet counts normalize on direct thrombin inhibitor therapy, warfarin can be initiated for long-term anticoagulation of HIT thrombosis. The warfarin therapy must be bridged with a direct thrombin inhibitor until a therapeutic international normalized ratio (INR goal 2.5, therapeutic range 2.0–3.0) has been reached. Of note, argatroban significantly increases pro-time and INR, so concomitant warfarin therapy requires special management.(97)

Tissue Plasminogen Activator

t-PA cleaves plasminogen into the active proteolytic enzyme plasmin. Unlike urokinase and streptokinase, t-PA is a relatively fibrin-selective plasminogen activator. In vitro experiments have shown plasminogen to have higher affinity for t-PA-bound fibrin, thereby having a local activation of plasmin and thrombin lysis. The American College of Chest Physicians (ACCP) guidelines for use of thrombotic therapy in venous thromboembolic (97) disease recommend the use of t-PA in hemodynamically unstable patients diagnosed with PE (Grade 2B). However, the use of t-PA in hemodynamically stable PE patients with right ventricular dysfunction has come under scrutiny.(101) In a small randomized study of 101 hemodynamically stable patients diagnosed with PE and right ventricular dysfunction, Goldhaber et al. (102) administered 100 mg t-PA followed by heparin infusion and compared them to those who received heparin alone. There were no episodes of recurrent PE in the t-PA group compared to five patients in the heparin group ($p = 0.06$). Right ventricular wall movement improved in twice as many patients in the t-PA group compared to the heparin-treated patients. Konstantinides et al. (103) reviewed the use of t-PA 10 mg intravenous bolus followed by a 90 mg infusion over 2 h followed by a heparin infusion compared to a heparin infusion alone in 256 hemodynamically stable patients with right ventricular dysfunction. Of note, trauma within the preceding 10 days was an exclusion criterion for study entrance. The primary end point (combined death and escalation of therapy defined as catecholamine infusion, open-label thrombolysis, endotracheal intubation, CPR[AU: PLEASE EXPAND CPR], or embolectomy) occurred in 10% of t-PA plus heparin-treated

patients compared to 25% of the heparin-only group ($p = 0.006$). No significant bleeding was noted in either group. However, the paucity of literature in the trauma population and in hemodynamically stable patients currently precludes the use of t-PA in these populations.(97, 101)

Warfarin

Warfarin, the only orally available therapeutic anticoagulant, inhibits vitamin K-dependent clotting factor synthesis through prevention of vitamin K_1 epoxide regeneration, which effectively reduces circulating clotting factors II, VII, IX, X and anticoagulants protein C and S. Warfarin dosing is patient specific and is titrated to indication as well as patient response. Before initiation of warfarin, a baseline complete blood count, pro-time, and INR need to be drawn. Treatment of DVT or PE requires achieving a therapeutic INR between 2.0 and 3.0 (23). In the setting of acute VTE, warfarin therapy is bridged with UFH, LMWH, or fondaparinux until the INR is within therapeutic range. In general, warfarin dose changes should not occur more frequently than every third day. The anticoagulation bridge process takes approximately 5 days to 1 week to complete. In patients with reversible risk factors for PE, warfarin therapy is recommended to continue for a minimum of 3 months.(97) The primary adverse effect of warfarin is bleeding with an annual incidence of major bleeding (requiring > 2 units transfused packed red blood cells) ranging from 1 to 10%. However, in the event of a major bleed, the INR can be effectively reversed by administration of fresh frozen plasma or vitamin K.(97)

> A saddle pulmonary embolus is diagnosed on spiral CT, and subsequently a deep vein thrombus is discovered in the patient's proximal left femoral vein by duplex ultrasound. The patient is hemodynamically stable and is considered to have a submassive PE. The case patient is initiated on a weight-based enoxaparin regimen (1 mg/kg SQ BID), and warfarin is started on the second day of therapy. After several days of combination anticoagulant therapy, the patient is successfully bridged to warfarin monotherapy (INR 2.2).

30 Days After Injury, the Patient Is Cleared to Ambulate. If He Has a retrievable Inferior Vena Cava Filter, Should It Be Removed?

In cases of contraindication to therapeutic anticoagulation, the filter can be removed when the contraindication has subsided and therapeutic anticoagulation can be started. Initially approved for permanent implantation, three filters have had changes in their Information for Use approved by the FDA to allow for the endovascular retrieval: the Günther Tulip™ (Cook, Inc., Bloomington, Ill.), the OptEase™ (Cordis Endovascular, Warren, NJ), and the Recovery® (CR Bard Inc., Murray Hill, NJ).(104) The recovery filter is no longer commercially available and has been replaced by a similar modified version called the G2 (Bard, Murray Hill, NJ). The

safety and feasibility of the insertion and removal of these devices in trauma patients has recently been demonstrated.

Guidelines for the management of patients with retrievable filters have been formulated by the consensus panel sponsored by the Society of Interventional Radiology.(105) These guidelines provide direction for when the filters can be safely removed and management of patients with both established VTE and those who had filters placed for prophylactic indications. Of note, this consensus panel states that patients without a known source of VTE should undergo duplex venous ultrasound before discontinuation of filtration. A finding of DVT with these patients requires postponement of filter discontinuation and initiation of primary therapy if possible. Furthermore, the panel recommends that imaging of the filter and the entire vena cava (with contrast-enhanced CT, MRV, or ultrasound) is mandatory prior to discontinuation of the filter. Substantial filling defects within the filter represent a significant risk for embolism during the retrieval process. The filter discontinuation procedure should be terminated, and appropriate primary therapy should be instituted. Reassessment for discontinuation of filtration may be considered at a later time.

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29 Shock

Jill Cherry-Bukowiec and Lena M Napolitano

A 70-year-old man with a history of compensated congestive heart failure (CHF) presents to the Emergency Department with abdominal pain. His physical examination confirms diffuse peritonitis. His systolic blood pressure is 100 mmHg and heart rate (HR) is 100 beats per minute. Laboratory evaluation confirms a serum creatinine of 2.1 and a leukocytosis with a white blood cell count (WBC) of 23,000. An upright chest radiograph demonstrates free air.

IS THIS PATIENT IN SHOCK?

To determine if this patient is in shock, we must first understand the definition of shock and presenting signs and symptoms of shock.

SHOCK: GENERAL OVERVIEW

Fundamentally, shock is tissue hypoperfusion. Shock is defined physiologically as inadequate delivery of substrates and oxygen to meet the metabolic demands of the tissues. When cells receive inadequate oxygen and substrate, they can no longer sustain efficient aerobic oxygen production. Aerobic metabolism generates 36 adenosine-5'-triphosphate ATP molecules per glucose molecule. As oxygen delivery (DO_2) is impaired, cells must switch to the much less efficient anaerobic metabolic pathway which generates only two ATP molecules per molecule of glucose, with resultant production and accumulation of lactic acid.

Common clinical manifestations of all types of shock include relative hypotension, tachycardia, poor skin perfusion, and organ system dysfunction. Signs of organ system dysfunction include oliguria (renal hypoperfusion) and altered mental status (brain hypoperfusion). In this patient with relative hypotension and tachycardia, we must suspect this patient may be in the early stages of shock. We should determine what his baseline blood pressure and heart rate values are in order to better interpret his current vital signs. He has an elevated serum creatinine which may reflect renal hypoperfusion, but we should determine what his baseline creatinine is. His clinical presentation is concerning for abdominal sepsis and septic shock from perforated viscus.

WHAT ARE THE BROAD CATEGORIES OF SHOCK?

Shock can be caused by a multitude of conditions which result in tissue hypoperfusion which can be divided into four main categories: Hypovolemic, Obstructive, Cardiogenic, and Distributive shock. Depending on the cause of a shock state, the manifestation (signs and symptoms) may be very different, and these are depicted in Table 29.1. Distributive shock, including septic shock, commonly manifests as "warm shock" with a vasodilated state, warm perfused skin, whereas hypovolemic shock manifests as "cold shock" with vasoconstricted hypoperfused skin.

Table 29.1 Hemodynamic Changes in Shock.

TYPE		HR	CVP	CO	SVR	VO$_2$ SAT
Hypovolemic		High	Low	Low	High	Low
Obstructive		High	High	Low	High	Low
Cardiogenic		High	High	Low	High	Low
Distributive	Anaphylactic	High	Low	Low	Low	Low
	Neurogenic	Low	Low	Low	Low	Low
	Hyperdynamic septic	High	Low/high	High	Low	High
	Hypodynamic septic	High	Low/high	Low	High	Low/high

HR= heart rate, CVP= central venous pressure, SVR= systemic vascular resistance, VO$_2$ SAT= venous oxygen saturation

Hypovolemic Shock

Hypovolemic shock is related to low of intravascular volume. There are a number of etiologies of hypovolemic shock, including excessive fluid losses as in severe diarrhea (gastroenteritis), high output fistulas, high gastric output (intestinal obstruction), excessive diuresis (diuretic therapy, diabetes insipidus, hyperosmotic states, diabetic ketoacidosis, dialysis) inadequate fluid intake (dehydration), and *Hemorrhagic Shock.*(1)

Hemorrhagic shock is unique form of hypovolemic shock as tissue hypoperfusion is a direct result of bleeding. Although often associated with traumatic injury, hemorrhagic shock can also be the result of gastrointestinal bleeding, ruptured aneurysm, hemorrhagic liver or splenic cysts, uterine hemorrhage, and surgical procedures to list just a few. Hemorrhagic shock, regardless of the source of bleeding, can be categorized into four classes, which can assist the clinician in assessment and successful management of the patient.(2) These classes are described in Table 29.2. In contrast, pediatric hemorrhage is classified as either mild, moderate or severe volume loss and are described in Table 29.3.

> It is possible that our patient has a hypovolemic form of shock as he is both tachycardic and hypotensive. We do not have information regarding urine output.

Obstructive Shock

Obstructive shock is tissue hypoperfusion as a result of a physical obstruction to blood flow. Tension pneumothorax, abdominal compartment syndrome, and late term pregnancies can compress the inferior vena cava, thereby decreasing venous return (preload) to the heart. Pericardial tamponade and superior vena caval syndrome can also reduce preload, ultimately

Table 29.2 Classes of Hemorrhagic Shock—Adult.

	Class			
	I	II	III	IV
Blood loss (ml)	< 750	750–1,500	1,500–2,000	> 2,000
Blood loss (%)	< 15	15–30	30–40	> 40
Heart rate (beats/min)	< 100	> 100	> 120	> 140
Blood pressure	Normal	Normal	Decreased	Decreased
Pulse pressure	Normal or increased	Decreased	Decreased	Decreased
Respiratory rate (breaths/min)	14–20	20–30	30–40	> 35
Urine output (ml/hour)	> 30	20–30	5–15	Minimal
Mental status	Normal or slightly anxious	Mildly anxious	Very anxious and/or confused	Very confused and/or lethargic

Modified from the Committee on Trauma: Advanced Trauma Life Support Manual 7th Edition, Chicago: American College of Surgeons 2004, page 74.

Table 29.3 Systemic Reponses to Hemorrhage—Child.

	Mild volume loss	Moderate volume loss	Severe volume loss
	< 30%	30–45%	> 45%
Cardiovascular	Tachycardia Normal blood pressure Weak peripheral pulses	Tachycardia Low–normal blood pressure Weak central pulses Narrow pulse pressure	Tachycardia, then bradycardia Hypotension
Mental status	Anxious, irritable	Confused, lethargic, dulled response to pain	Unresponsive
Skin	Cool, mottled, prolonged capillary refill	Cyanotic, prolonged capillary refill	Pale, cold
Urinary Output	Minimal	Minimal	None

Modified from the Committee on Trauma: Advanced Trauma Life Support Manual 7th edition, Chicago: American College of Surgeons 2004, page 251

resulting in hypotension and tissue hypoperfusion. Another source for obstructive shock is a massive pulmonary embolism. Large pulmonary emboli lodge in the pulmonary arteries thereby obstructing left ventricular filling with resultant increased right heart pressures and right ventricular failure. By the history given, it is unlikely our patient has experienced one these events.(1)

Cardiogenic Shock

Cardiogenic shock is tissue hypoperfusion due to heart failure. Either the heart muscle or the valves are dysfunctional. When the heart cannot contract effectively, cardiac output and blood pressure decrease, there is an increase in left ventricular filling pressures, and compensatory tachycardia and systemic vasoconstriction (increased systemic vascular resistance) ensue. Although this patient has a history of compensated heart failure, without clinical evidence of pulmonary edema and with the findings of free air on chest radiograph in addition to an elevated white blood cell count (WBC) of 23,000, another source for our patient's condition must be considered.(1)

Distributive Shock

Distributive shock is a state in which tissue hypoperfusion occurs as a result of decreased systemic vascular tone, which re-distributes the patient's intravascular volume. *Anaphylactic, neurogenic, and septic shock* can all be considered types of distributive shock. Each category, however, has a distinct pathophysiology and unique hemodynamic manifestations (Table 29.4).(3)

Anaphylactic shock is tissue hypoperfusion secondary to rapid systemic vasodilatation. The systemic vasodilatation is triggeredby a type I hypersensitivity allergic reaction mediated by immunoglobulin E (IgE). IgE stimulates simultaneous degranulation of mast cells and/or basophils to release immunological mediators, such as histamines, leukotrienes, and prostaglandins into the systemic circulation.(3) The patient subsequently experiences hypotension from systemic vasodilatation and bronchospasm. Recent literature suggests that up to 1–2% of the population may be at risk.(4) Some common allergens include insect bites, penicillin, neuromuscular blocking agents, and latex.(5) Treatment is focused at removal of the inciting allergen, restoration of circulating blood volume through intravenous fluids, and reversal of the vasodilatation, usually through the administration of epinephrine.(6)

Neurogenic shock results from acute injury to the cervical spinal cord. It is characterized by significant hypotension with a concurrent drop in heart rate. This is attributed to the high cervical spinal cord injury causing a disruption in sympathetic neural pathways resulting in decreased peripheral sympathetic tone and cessation of sympathetic input to the heart. It is suggested that without the counterbalance of sympathetic stimulation, the unopposed vagal activity on the heart produces bradycardia.(7, 8)

Septic shock is a form of distributive shock where an infectious process incites a systemic inflammatory response causing systemic vasodilatation leading to inadequate preload and low cardiac output.(9) Hypotension, tissue hypoperfusion, and organ failure then follow. The definition of septic shock is the presence of two or more systemic inflammatory response syndrome (SIRS) criteria with a presumed or confirmed infectious process and evidence of tissue hypoperfusion. Our patient meets two of the SIRS criteria (HR > 90 and WBC ≥ 12,000) (Table 29.5 and Figure 29.1). Additionally, the finding of free air on chest radiograph is highly suggestive of a perforated intestine, such as a duodenal ulcer or perforated diverticulitis, raising concern for an intra-abdominal infectious process.

Table 29.4 Hemodynamic Changes in Distributive Shock.

type	BP	HR	CVP	CO	SVR	VO2 SAT
Anaphylactic	Low	High	Low	Low	Low	Low
Neurogenic	Low	Low	Low	Low	Low	Low
Hyperdynamic septic	Low	High	Low/high	High	Low	High
Hypodynamic septic	Low	Low/high	Low/high	Low	High	Low/high

BP = blood pressure, HR = heart rate, CVP = central venous pressure, SVR = systemic vascular resistance, VO2 SAT = venous oxygen saturation.

Table 29.5 Surviving Sepsis Campaign—Definitions.

Term	Definition
SIRS	A clinical response arising from a nonspecific insult, including ≥ two of the following: Temperature ≥ 38 or ≤ 36 C Heart rate (HR) ≥ 90 beats/min Respirations ≥ 20/min WBC ≥ 12,000/mm³ or ≤4,000/mm³ or > 10% neutrophils
Sepsis	SIRS with a presumed or confirmed infectious process
Severe sepsis	Sepsis with ≥ 1 sign of organ failure: Cardiovascular (refractory hypotension) Renal Respiratory Hepatic Hematologic Central nervous system Metabolic acidosis
Septic shock	Sepsis-induced hypotension, despite adequate fluid resuscitation, with presence of perfusion abnormalities

(10–12)

The patient has evidence of septic shock and warrants prompt initiation of treatment for septic shock. The evidence-based sepsis guidelines ("Surviving Sepsis Campaign International Guidelines for Management of Severe Sepsis and Septic Shock") were first published in 2004, and just recently updated in 2008. (10–12) These guidelines were developed through an international collaboration of leading critical care organizations reviewing the best available evidence over the past two decades. The key recommendations are listed in Table 29.6, with evidence graded by the Grades of Recommendation, Assessment, Development and Evaluation (GRADE) system to guide assessment of quality of evidence from high (A) to very low (D) and to determine the strength of recommendations. A strong recommendation (1) indicates that an intervention's desirable effects clearly outweigh its undesirable effects (risk, burden, cost) or clearly do not. Weak recommendations (2) indicate that the tradeoff between desirable and undesirable effects is less clear. The grade of strong or weak is considered of greater clinical importance than a difference in letter level of quality of evidence. In areas without complete agreement, a formal process of resolution was developed and applied. Recommendations are grouped into those directly targeting severe sepsis, recommendations targeting general care of the critically ill patient that are considered high priority in severe sepsis, and pediatric considerations. A guide to this grading system is provided in Table 29.7.(13)

These guidelines have been compiled into practice care bundles entitled the sepsis "resuscitation" bundle and sepsis "management" bundle to guide early treatment which can be initiated for this patient.(12) (Tables 29.8 and 29.9). It has been shown that compliance with the 6-h sepsis bundle was associated with a significant reduction in hospital mortality rate (Figure 29.2).(13)

WHAT ADDITIONAL INFORMATION WOULD BE HELPFUL TO DETERMINE SEVERITY OF SHOCK? WHAT ARE THE APPROPRIATE MONITORING DEVICES AND BLOOD TESTS FOR THIS PATIENT?

Determining severity of shock can be accomplished by multiple different methods. Laboratory values such as lactate levels, base deficit, anion gap (AG), and serum bicarbonate levels have been used to indicate the severity of tissue hypoperfusion and its effect on the body's homeostatic mechanisms.(15) Additionally, return of these laboratory values to normal has been used as an end point of resuscitation. However, only restoration of normal lactate levels has been correlated with improvements in mortality and is recommended for use as an end point of resuscitation by the Surviving Sepsis Guidelines.(16)

Lactic acid is produced during anaerobic metabolism. Under normal circumstances the human body's blood lactate concentration is < 2 mmol/L. Hyperlactatemia or lactic acidosis (blood lactate levels ≥ 4 mmol/L) is considered a sign of a hypoperfusion state (shock) in patients with evidence of sepsis.(15) In the seminal paper by Rivers et al. hypotension and elevated serum lactate levels were used to identify patients in shock. Intervening early with "early goal-directed therapy" was associated with significantly increased survival rates.(16) Additionally, lactate clearance is associated with improved outcomes in patients with septic shock and is a marker by which clinicians can monitor the effectiveness of their interventions.(17) These findings have been incorporated into the Surviving Sepsis Guidelines.(12)

Base deficit is the amount of base required to return the pH of blood back to neutral (7.40 in human blood), as Base excess (BE) defines the amount of acid required to return the pH of blood back to neutral. The normal range of base in human blood is −2 to +2 mmol/L. When there is a base deficit (negative bases excess), the patient is considered to be acidotic. The BE can be calculated from a derivative of the Henderson–Hasselbalch equation (B.E. = $0.02786 * pCO2 * 10^{(pH-6.1)} + 13.77 * pH - 124.58$) but this is usually unnecessary, as most arterial blood gas analyzers calculate the BE. The base deficit has been uses as a surrogate to predict hyperlactatemia in the presence of metabolic acidosis. Unfortunately, recent studies have concluded that base deficit is not a reliable indicator of lactic acidosis.

AG represents the unmeasured ions in blood plasma and is calculated using the formula: AG = $[Na^+] - ([Cl^-] + [HCO_3^-])$. Because lactate is an organic acid, it has been thought that an elevated AG could be used as a surrogate marker for hyperlactatemia. Many critically
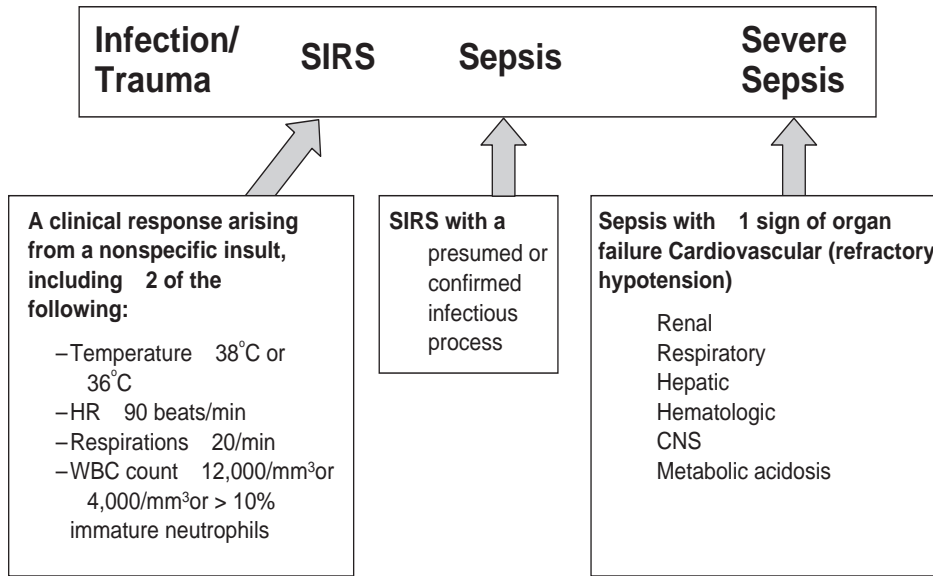
Figure 29.1 Definitions of SIRS (Systemic inflammatory response syndrome), sepsis and severe sepsis. From: Bone et al. Chest 1992; 101: 1644.

Table 29.6 Surviving Sepsis—Key Recommendations.

	Grade
Early goal-directed resuscitation of the septic patient during the first 6 h after recognition	1C
Blood cultures before antibiotic therapy	1C
Imaging studies performed promptly to confirm potential source of infection	1C
Administration of broad-spectrum antibiotic therapy within 1 h of diagnosis of septic shock	1B
Severe sepsis without septic shock	1D
Reassessment of antibiotic therapy with microbiology and clinical data to narrow coverage, when appropriate	1C
A usual 7–10 days of antibiotic therapy guided by clinical response	1D
Source control with attention to the balance of risks and benefits of the chosen method	1C
Administration of either crystalloid or colloid fluid resuscitation	1B
Fluid challenge to restore mean circulating filling pressure	1C
Reduction in rate of fluid administration with rising filing pressures and no improvement in tissue perfusion	1D
Vasopressor preference for norepinephrine or dopamine to maintain an initial target of mean arterial pressure (MAP) > or = 65 mmHg	1C
Dobutamine inotropic therapy when cardiac output remains low despite fluid resuscitation and combined inotropic/vasopressor therapy	1C
Stress-dose steroid therapy given only in septic shock after blood pressure is identified to be poorly responsive to fluid and vasopressor therapy	2C
Recombinant activated protein C in patients with severe sepsis and clinical assessment of high risk for death (2B except 2C for postoperative patients)	2B or 2C
In the absence of tissue hypoperfusion, coronary artery disease, or acute hemorrhage, target a hemoglobin of 7–9 g/dL	1B
A low tidal volume (1B) and limitation of inspiratory plateau pressure strategy (1C) for acute lung injury (ALI)/acute respiratory distress syndrome (ARDS)	1B and 1C
Application of at least a minimal amount of positive end-expiratory pressure in ALI	1C
Head of bed elevation in mechanically ventilated patients unless contraindicated	1B
Avoiding routine use of pulmonary artery catheters (PAC) in ALI/ARDS	1A
To decrease days of mechanical ventilation and intensive care unit (ICU) length of stay, a conservative fluid strategy for patients with established ALI/ARDS who are not in shock	1C
Protocols for weaning and sedation/analgesia (1B); using either intermittent bolus sedation or continuous infusion sedation with daily interruptions or lightening (1B)	1B and 1B
Avoidance of neuromuscular blockers, if at all possible	1B
Institution of glycemic control (1B), targeting a blood glucose < 150 mg/dL after initial stabilization (2C)	1B and 2C
Equivalency of continuous veno–veno hemofiltration or intermittent hemodialysis	2B
Prophylaxis for deep vein thrombosis	1A
Use of stress ulcer prophylaxis to prevent upper gastrointestinal bleeding using H2 blockers (1A) or proton pump inhibitors (1B)	1A and 1B
Consideration of limitation of support where appropriate	1D

Table 29.7 Grades of Recommendation, Assessment, Development, and Evaluation (GRADE) System.

Grading of Recommendations	
A	Supported by at least two level 1 investigations
B	Supported by one level I investigation
C	Supported by level II investigations only
D	Supported by at least one level III investigation
E	Supported by level IV or V evidence
Grading of Evidence	
I	Large, randomized trials with clear-cut results: low risk of false-positive (alpha) error or false negative (beta) error
II	Small, randomized trials with uncertain results; moderate-to-high risk of false-positive (alpha) and/or false-negative (beta) error
III	Nonrandomized, contemporaneous controls
IV	Nonrandomized, historical controls and expert opinion
V	Case series, uncontrolled studies, and expert opinion
(13)	

Table 29.8 Sepsis Resuscitation Bundle.

To be started immediately and completed within 6 h of suspecting sepsis
Serum lactate measured
Blood cultures obtained prior to antibiotic administration
Broad-spectrum antibiotics administered within 1 h of diagnosis of severe sepsis and septic shock
In the event of hypotension and/or lactate > 4 mmol/L: Deliver a minimum of 20 ml/kg of crystalloid (or colloid equivalent) Apply vasopressors for hypotension not responding to initial fluid resuscitation to maintain MAP ≥ 65 mmHg
In the event of persistent arterial hypotension despite volume resuscitation (septic shock) and/or initial lactate > 4 mmol/L (36 mg/dl): Achieve central venous pressure (CVP) of ≥ 8 mmHg Achieve central venous oxygen saturation (ScVO$_2$) of ≥ 70%*.
(12)

*Achieving a mixed venous oxygen saturation of 65% is an acceptable alternative.

Table 29.9 Sepsis Management Bundle.

To be started immediately and completed within 24 h
Low-dose steroids administered for septic shock in accordance with a standardized ICU policy
Drotrecogin alfa (activated) administered in accordance with a standardized ICU policy
Glucose control maintained ≥ lower limit of normal, but < 150 mg/dl (8.3 mmol/L)
For mechanically ventilated patients inspiratory plateau pressures maintained < 30 cm H$_2$O
(12)

ill patients, however, have hypoalbuminemia, and since albumin has a high negative charge, it can confound the AG calculation. To account for the low albumin often observed in critically in patients, some researchers have suggested correcting for low albumin in AG calculations: ({4.4–[observed serum albumin (g/dL)] × 0.25} + AG) (The Figge equation).(18) Again, recent studies have failed to show a direct correlation between lactate levels and AG.(19)
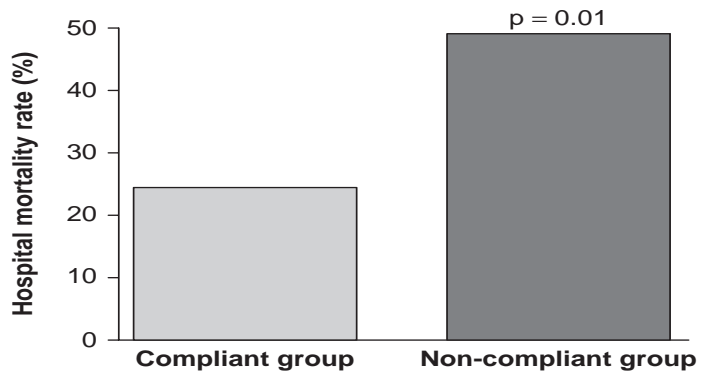
Figure 29.2. Compliance with the 6-hour sepsis bundle was associated with a significant reduction in hospital mortality rate. (From Gao F et al) [14]

Table 29.10 Common Crystalloid Solutions.

	Contents in 1 L	mOsm/L
Normal saline (0.9% NaCL)	154 mEq of sodium ion = 154 mmol/L 154 mEq of chloride ion = 154 mmol/L	310
Lactated ringers	130 mEq of sodium ion = 130 mmol/L 109 mEq of chloride ion = 109 mmol/L 28 mEq of lactate = 28 mmol/L 4 mEq of potassium ion = 4 mmol/L 3 mEq of calcium ion = 1.5 mmol/L	272
Plasmalyte®R	140 mEq of sodium ion = 140 mmol/L 103 mEq of chloride ion = 103 mmol/L 8 mEq of lactate = 8 mmol/L 47 mEq acetate = 47 mmol/L 10 mEq of potassium ion = 10 mmol/L 5 mEq of calcium ion = 2.5 mmol/L 3 mEq of magnesium = 1.5 mmol/L	312
Normosol®R	140 mEq of sodium ion = 140 mmol/L 98 mEq of chloride ion = 98 mmol/L 23 mEq of gluconate = 23 mmol/L 27 mEq acetate = 27 mmol/L 5 mEq of potassium ion = 5 mmol/L 3 mEq of magnesium = 1.5 mmol/L	295

Serum bicarbonate (HCO$_3^-$) is one of the principal buffering mechanisms within human blood and has been shown to decrease linearly as acid loads increase.(20, 21) Recent studies have shown a high degree of correlation between blood serum bicarbonate levels and base deficit in their ability to predict metabolic acidosis, but blood bicarbonate is not an accurate surrogate marker for lactate and is not recommended as an end point of resuscitation in the 2008 Surviving Sepsis Guidelines.(22, 12)

WHAT ARE THE APPROPRIATE FLUIDS WITH WHICH TO INITIATE FLUID RESUSCITATION?

Fluid challenges of 1,000 mL of isotonic crystalloids or 300–500 mL of colloids over 30 min have been recommended for fluid resuscitation in sepsis and septic shock by the Surviving Sepsis Guidelines. A list of commonly used isotonic fluids can be found in Table 29.10. It is also recognized that more rapid and larger volumes may be required in patients with severe septic shock

and sepsis-induced tissue hypoperfusion and in patients with a component of hypovolemic shock as well as septic shock.(12)

The decision regarding whether to use isotonic crystalloid solution or a colloid solution such as albumin has been a topic of debate in the medical community for many years. The Saline vs. Albumin Fluid evaluations (SAFE) study (23) enrolled nearly 7,000 critically ill patients who were randomized to albumin 4% vs. normal saline and documented no difference in 28-day all-cause mortality, ICU or hospital length of stay, days of mechanical ventilation or renal replacement therapy. This study clearly documented that albumin has no clear benefit in the fluid resuscitation of the majority of critically ill patients.(24)

A subgroup analysis of the SAFE Study documented that among patients with trauma (n=1,186), albumin was associated with a trend toward *increased* mortality (RR 1.36; 95% CI 0.99–1.86), particularly in patients with traumatic brain injury. Another subgroup analysis of patients with severe sepsis (n = 1,218) documented that albumin use was associated with a trend toward *reduced* mortality (RR 0.87, 95% CI 0.74–1.02). These results must be interpreted with caution, particularly in light of emerging data documenting that albumin administration in sepsis redistributes much more quickly than in normal controls consistent with the general concept of "capillary leak syndrome". (25) The SAFE study cohort was also analyzed to determine the effect of baseline serum albumin concentration ($\leq$ 2.5 g/dL vs. > 2.5 g/dL) on outcome of resuscitation, and no difference was identified in 28-day all-cause mortality, ICU or hospital length of stay, duration of renal replacement therapy, or duration of mechanical ventilation.(26)

The substantial differences in the wholesale costs of these two therapies is notable ($232 for 1 l of 5% albumin; $2.32 for 1 l of saline) with the cost for each patient treated in the SAFE study estimated at $521.30 for albumin compared to $6.90 for saline, a 75-fold difference.(27) These cost differences suggested that the routine use of albumin is hard to justify since crystalloid use is associated with similar outcomes at a lower cost. But some clinicians may interpret the SAFE study to have documented an absence of harm associated with albumin and will continue to use it based on presumed potential benefit in select patients.(28)

More recently, the results of the Sepsis Occurrence in Acutely ill Patients (29) study, a prospective multicenter observational cohort study (n = 3,147) conducted in Europe, examined albumin use and outcomes. Interestingly, 354 (11.2%) of patients received albumin and most (n = 157, 44.4%) received it during the first 24 h after ICU admission. Albumin administration was independently associated with decreased 30-day survival (HR 1.57, 95% CI 1.11–2.22, p = 0.012) in this population of critically ill patients of which 1,388 (44.1%) were surgical patients. Furthermore, surgical patients were the largest cohort to receive albumin, comprising 218 of the 354 patients that receiving albumin during the study period.

Regardless of which resuscitation fluid is used, a target CVP of 8 mmHg (12 mmHg if mechanically ventilated) has been suggested as a resuscitation goal in sepsis and septic shock. A recent systematic review demonstrated a very poor relationship between CVP and blood volume as well as the inability of the change in CVP to predict the hemodynamic response to a fluid challenge and concluded that CVP should not be used to make clinical decisions regarding fluid management.(30) Alternatively, clinicians can use changes in vital signs and urine output, and normalization of lactate as end points of resuscitation. Additionally, the rate

of fluid administration should be reduced if cardiac filling pressures increase without concurrent hemodynamic improvement. If fluid challenges fail to improve the septic patient's hemodynamics, vasopresser agents should be considered and initiated.(12)

SHOULD ANTIBIOTICS BE ADMINISTERED? IF SO, WHEN? WHAT CLASS OF ANTIBIOTICS SHOULD BE GIVEN?

Broad-spectrum antibiotic therapy should be started *within the first hour* of suspecting sepsis or septic shock. A recent multi-center retrospective review documented that with every hour that effective antibiotic administration was delayed, there was a measurable increase in mortality.(31) When possible, cultures should be obtained prior to the administration of antibiotics, but it is imperative that antibiotic administration not be delayed for collection of the specimens.(12) Initial antibiotics should be broad-spectrum that have activity against all likely pathogens (bacterial and/or fungal) with good penetration into the site of the presumed source of infection.(12, 31) A number of studies have documented that inadequate antimicrobial therapy (i.e., empiric antibiotics administered that did not cover the final pathogens) is associated with increased mortality in sepsis patients.(32)

With the finding of pneumoperitoneum (free air on chest radiograph) in this patient, it is prudent to suspect a hollow viscus injury and abdominal infection as the most likely source of sepsis. Peritonitis can be classified into three classifications: Primary, Secondary, and Tertiary. Primary peritonitis also known as spontaneous bacterial peritonitis and is an intra-abdominal infection arising *without* violation of the gastrointestinal tract. Primary peritonitis is most common in patient with hepatic insufficiency and ascites and the most common pathogen is *Escherichia coli*. The pathophysiology of primary peritonitis is that enteric bacteria translocate across the intact gastrointestinal wall and proliferate in the peritoneal cavity. Diagnosis is often established through paracentesis with > 500 white cells/mm^3 of ascitic fluid, a reduced glucose level, and/or and elevated lactate with subsequent culture growth of a single strain of bacteria or fungus (Figure 29.3).(33)

In contrast, *secondary peritonitis* is a result of a breach in the gastrointestinal tract wall, through perforation, necrosis, or injury. Cultures often yield polymicrobial organisms (Figure 29.3). As gastric contents travel down thorough the GI tract, bacterial loads increase (Figure 29.4). Source control is required for cure of secondary peritonitis.(33) *Tertiary peritonitis* is defined as intra-abdominal infection that persists or recurs >48 h after definitive management of a primary or secondary peritonitis. Tertiary peritonitis has quite a different microbial profile from primary and secondary peritonitis with greater likelihood of resistant pathogens (Figure 29.3) and can be challenging to eradicate.(33)

Choosing effective empiric antibiotic coverage for sepsis and septic shock is imperative to a patient's survival.(12, 31) The Surgical Infection Society and the Infectious Disease Society of America have published recommended antimicrobial regimens for intra-abdominal infections to guide clinicians in selecting appropriate coverage (Figure 29.5).(34, 35) Once the cultures have pathogen identification and antibiotic sensitivities are known, de-escalation from broad spectrum antibiotics to more focused, targeted therapy should be initiated to optimize efficacy, prevent resistance, and minimize costs.(12)

Microbiology of Peritonitis

Primary (monomicrobial)	Secondary (polymicrobial)	Tertiary (polymicrobial)
E. coli	*B. fragilis* group	*Enterococci*
Klebsiella spp	*E. coli*	*Pseudomonas*
Streptococcus spp	*Clostridium* spp	*S. epidermidis*
Enterococcus spp	*Klebsiella* spp	*Candida*
Other gram-negative bacilli	*Streptococcus* spp	
	Enterococcus spp	
	Pseudomonas spp	

S. anginosus

E. coli

B. fragilis

S. epidermidis

Barie PS. *J Chemother.* 1999;11:464-477.
LaRoche M, Harding G. *Eur J Clin Microbiol Infect Dis.* 1998;17:542-550.

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Figure 29.3 Common bacterial profiles of Primary, Secondary, and Tertiary Peritonitis.(36, 37)

The patient receives 3 L of intravenous fluids that restore his systolic blood pressure and heart rate to 140 mmHg and 80 beats per minute, respectively. What is the next step in this patient's care?

SOURCE CONTROL

The Surviving Sepsis Guidelines recommend early specific anatomic diagnosis of infection and consideration for emergent source control within the first 6h following presentation. When source control is required, the effective intervention associated with the least physiologic insult should be employed.(12) Source control is a fundamental component in the successful treatment of sepsis and septic shock. In order to halt ongoing microbial contamination the infectious source must be contained, drained, or removed. Although source control has been the mainstay and thought to be essential in the treatment of the septic patient, most recommendations are graded as D or E due to the fact that designing appropriate randomized clinical trials is impractical and against the current standard of care. Most clinicians believe such a trial would put patients at serious unnecessary risk.(39)

Our patient responds to his fluid challenge and is taken to the operating theater where he underwent a Hartman's procedure for perforated sigmoid diverticulitis. He is transported intubated to the SICU. Within the first few hours after arrival to the ICU the patient becomes oliguric. How can it be determined if the patient is hypovolemic? What are the appropriate monitoring devices for this patient?

Hypovolemia can be inferred by hypotension, tachycardia, and other signs of inadequate tissue perfusion. Once fluid resuscitation has been initiated and a patient's hemodynamics have been restored, urine output should reflect improved perfusion. An adult human makes about 0.5 cc/kg/h in an adequately hydrated state. Persistent low urine output can be a sign of under-resuscitation, acute tubular necrosis (ATN), urinary tract obstruction, and/or renal failure. In this situation a urinary catheter should be placed in the patient's urinary bladder, if not already done. If it has been previously placed it should be re-evaluated for proper placement, clogs, and kinks. If the catheter is working properly, oliguria may reflect hypovolemia and inadequate resuscitation with resultant renal hypoperfusion. Alternatively, it may

Concentration of Bacterial Flora in Regions of the Gastrointestinal Tract
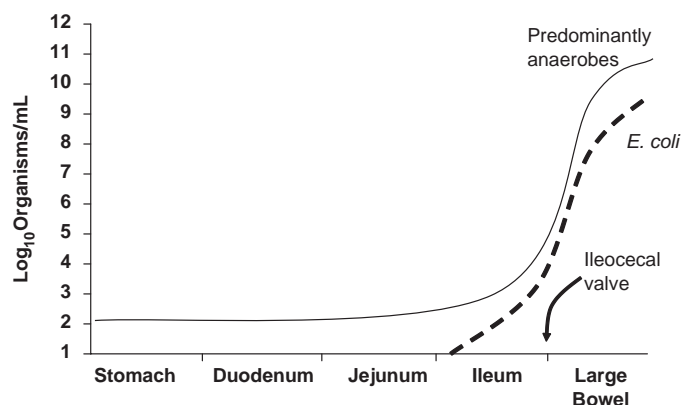
Figure 29.4 Concentration of Bacterial Flora in Regions of the Gastrointestinal Tract. Concentrations of organisms are relatively small in the stomach and small intestine, and logarithmically increase upon entering the large intestine (38).

Figure 29.5 Recommended antimicrobial regimens for complicated intra-abdominal infection and abdominal sepsis. (34,35)

reflect that the patient is developing acute renal failure. A fluid challenge and/or calculation of the Fractional excretion of Sodium (FeNa) or Fractional excretion of Urea (FeUrea) may also assist the practitioner in determining the reason for olgiuria. (Table 29.11) In 2002 Carvounis et al.(40) reported that low FeUrea (< 35%) was more sensitive and specific than low FeNa (< 1%) in differentiating between transient prerenal disease and ATN.(41)

In face of a history of congestive heart failure (CHF), it may be challenging to determine if the oliguria is a result of heart failure, inadequate resuscitation, primary renal failure, or is a result of a combination of processes. Brain natriuretic peptide (BNP) has been found to be useful tool in the diagnosis of acute cases of CHF (42), but the complex relationships involved in sepsis and septic shock may also cause an increase in BNP levels and has not been fully evaluated, thus making BNP an unreliable marker for CHF in septic patients.(43) In this case, consideration of invasive and noninvasive monitoring devices to evaluate preload, afterload, and cardiac contractility is prudent.

Central venous monitoring lines can give information about CVP. The Surviving Sepsis Guidelines recommend a goal CVP ≥ 8 mmHg (≥ 12 mmHg in ventilated patients).(12) Additionally, mixed venous oxygen saturation can be measured from a central venous line (ScVO$_2$). At specific wavelengths of light, deoxygenated hemoglobin and oxyhemoglobin absorb light differently. By using reflection spectrophotometry, the reflected light can be analyzed and measured to determine the central venous oxygen saturation (ScVO$_2$).(9) Rivers et al. found that a ScVO$_2$ goal of 65% correlated with favorable end points of resuscitation and has been recommended as a guide in the Surviving Sepsis Guidelines. (9, 12, 16)

Additional information can be obtained invasively from a PAC. CVP, pulmonary artery pressure, pulmonary capillary wedge pressure, cardiac output, and the mixed venous partial pressure of oxygen (SVO$_2$) can all be measured from a PAC; cardiac index, stroke volume, systemic vascular resistance, and pulmonary vascular resistance can also be derived. All these measurements can be useful in guiding resuscitation efforts and in deciphering septic shock from cardiogenic shock. Unfortunately, as PAC s are placed through central venous access and into the heart, they can be accompanied by significant risks, some of which can be life threatening. As with any centrally placed catheter complications can include pneumothorax, hemothorax, and infection. Cardiac arrhythmias and pulmonary artery rupture are additional hazards specific to intracardiac catheters. The first major compelling study advocating against the routine use of PAC s was published in 1996 by Connors and coworkers. This large observational study, evaluating the use of PACs in critically ill patients concluded that placement of a PAC during the first day of a patient's stay in an ICU is associated with a significant increase in mortality risk, even after severity of illness was risk adjusted.(44) Later studies confirmed that use of the PAC did not yield a survival advantage in critically ill patients (45) and its routine use in sepsis and septic shock patients is not recommended.(12)

Other less invasive monitoring devices have been effectively employed in the critical care patient, including echocardiography and Esophageal Doppler Monitors.(46, 9, 47)

Esophageal Doppler Monitoring devices use ultrasonic sound waves and their reflection off erythrocytes flowing through the aorta. The frequency of the reflected signal changes depending on whether the red blood cells are flowing toward or away from the ultrasonic probe, called the Doppler shift. The magnitude of the wave form is determined by the velocity of the erythrocytes. By calculating the mean velocity of flowing erythrocytes and estimating the cross-sectional area of the aorta, the blood flow rate and can be approximated from which the cardiac output can then be inferred.(9) Although there is mounting evidence that esophageal Doppler monitoring may be a safe acceptable alternative to the use of PACs, (48–60) further investigation into the utility and reliability of such devices is still needed before widespread use in sepsis patients can be recommended.(9)

Echocardiography has become an attractive alternative to the PAC as it is non-invasive and can also be performed at the patient's bedside. Additionally, the patient's global heart function, valve function, wall motion, as well as filling pressures, and cardiac output can be assessed. One drawback is that the echocardiogram is not a continuous monitoring device at the present time. Availability may be also limited in the ICU setting as most echocardiographers are cardiologists with busy practices and not all intensivists are trained in echocardiography. As the device gains in popularity, these obstacles may be overcome.

Table 29.11 Calculation of FeNa or FeUrea may assist in determination of the reason for oliguria in shock states.
To accurately interpret FE$_{Na}$, patients should not have recently received diuretics. Since the FE$_{Na}$ is reliant on the phenomenon that sodium reabsorption is enhanced in the setting of volume depletion, active use of diuretics may elevate the FE$_{Na}$ even when volume depletion is present. The fractional excretion of urea (FE$_{Urea}$) has been proposed as an alternative tool as urea excretion is not thought to be promoted by diuretics yet is still retained in volume depleted states. A FE$_{Urea}$ <. 35% is suggestive of a prerenal etiology of acute renal failure, while a FE$_{Urea}$ > 50% suggests ATN.

Test	Abbreviation	Equation	PreRenal Pre-renal states Hypovolemia Congestive heart failure Acute glomerulonephritis	PostRenal or ATN Acute tubular necrosis (ATN) Severe urinary obstruction Vasculitis Interstitial nephritis Intrinsic renal failure
Fractional Excretion of Sodium	FE$_{Na}$	$$FE_{Na} = \frac{U_{Na} * P_{Cr}}{P_{Na} * U_{Cr}} \times 100$$ [(urine sodium/ plasma sodium)/(urine creatinine/plasma creatinine)] X 100.	< 1%	> 1% (usually > 3%)
Fractional Excretion of Urea	FE$_{Urea}$	$$FE_{Urea} = \frac{U_{Urea} * P_{Cr}}{P_{Urea} * U_{Cr}} \times 100$$ [(urine urea nitrogen/ blood urea nitrogen)/(urine creatinine/plasma creatinine)] X 100.	< 35%	> 35% (usually > 50%)

Alternatively, another technique employed by some critical care practitioners is monitoring stroke volume variation during positive pressure ventilation via an arterial catheter. The intrathoracic pressure generated by mechanical ventilation produces cyclic variations in pulmonary artery blood flow, vena cava blood flow, and aortic blood flow. The magnitude of the variation has been found to be highly dependent on volume status—the greater the variation between the pressures, the lower the preload. The systolic pressure variation (also called stroke volume variation, arterial pressure waveform analysis, and pulse contour analysis) can be measured at the bedside via arterial catheter. Most studies have used the systolic pressure variation to evaluate responsiveness to fluid resuscitation, (59, 61, 57) however, some investigators are attempting to convert the systolic pressure variation readings into estimations of cardiac output.(56, 60, 62–64) More research in this area needs to be done before systolic pulse variation can be recommended as a reliable monitoring in critically ill patients.(62)

WHEN SHOULD BLOOD TRANSFUSION BE CONSIDERED?

According the Surviving Sepsis Guidelines transfusion should be considered when treating a patient with severe sepsis or septic shock if during the first 6 h of resuscitation a goal of ScVO$_2$ > 70% or the mixed venous oxygen saturation (SVO$_2$) > 65% is not reached with fluid resuscitation, and/or the CVP target of 8 mmHg (12 mmHg in ventilated patients), then transfusion of packed red blood cells to achieve a hematocrit of > 30% and/or administration of a dobutamine infusion (up to a maximum of 20 µg·kg^{-1}·min^{-1}) can be employed.(12) Grade 2C evidence. These recommendations were made based on the 2001 Rivers et al. protocol for "Early goal-directed therapy in the treatment of severe sepsis and septic shock." Two hundred and sixty-three patients were randomized to receive either early goal-directed therapy or standard therapy. The early goal directed therapy

group had a significantly decreased in-hospital mortality of 30.5% compared with 46.5% in the standard therapy group. Figure 29.6(16)

However, a previous multicenter randomized trial (Transfusion Requirements in Critical Care, TRICC trial) documented that a hemoglobin of 7–9 g/dL when compared with 10–12 g/dL was not associated with increased mortality in adults.(66) Other prospective cohort studies (CRIT, ABC trials) have shown worse outcomes when RBCs are liberally transfused in critically ill patients not suffering from angina or acute myocardial infarction.(65–67) An evidence-based review of the use of blood products in sepsis also concluded that "in the absence of extenuating circumstances and following resolution of tissue hypoperfusion, RBC transfusion should be targeted to maintain hemoglobin at 7.0 g/dL or greater."(68) The Surviving Sepsis Guidelines also state "Once tissue hypoperfusion has resolved, and in the absence of extenuating circumstances, such as myocardial ischemia, ischemia, severe hypoxemia, acute hemorrhage, cyanotic heart disease, or lactic acidosis, red blood cell transfusion should be given when hemoglobin decreases to < 7.0 g/dL to target a hemoglobin of 7.0 –9.0 g/dL (70–90 g/L) in adults. (Grade 1B).(12)

WHEN SHOULD VASOPRESSORS BE CONSIDERED?
WHAT PRESSORS/INOTROPES ARE DESIRABLE, IF NEEDED?

One of the key components of cardiovascular support in shock is to maintain an adequate mean arterial blood pressure to ensure tissue perfusion to the major organs. The recent Surviving Sepsis Campaign Guidelines have advocated the use of aggressive fluid resuscitation and, if hypotension persists, administration of either norepinephrine or dopamine to maintain a MAP > 65 mmHg (Figure 29.2). If vasopresser support is required, an arterial catheter should be inserted early to monitor the effectiveness of vasopresser therapy.(12)
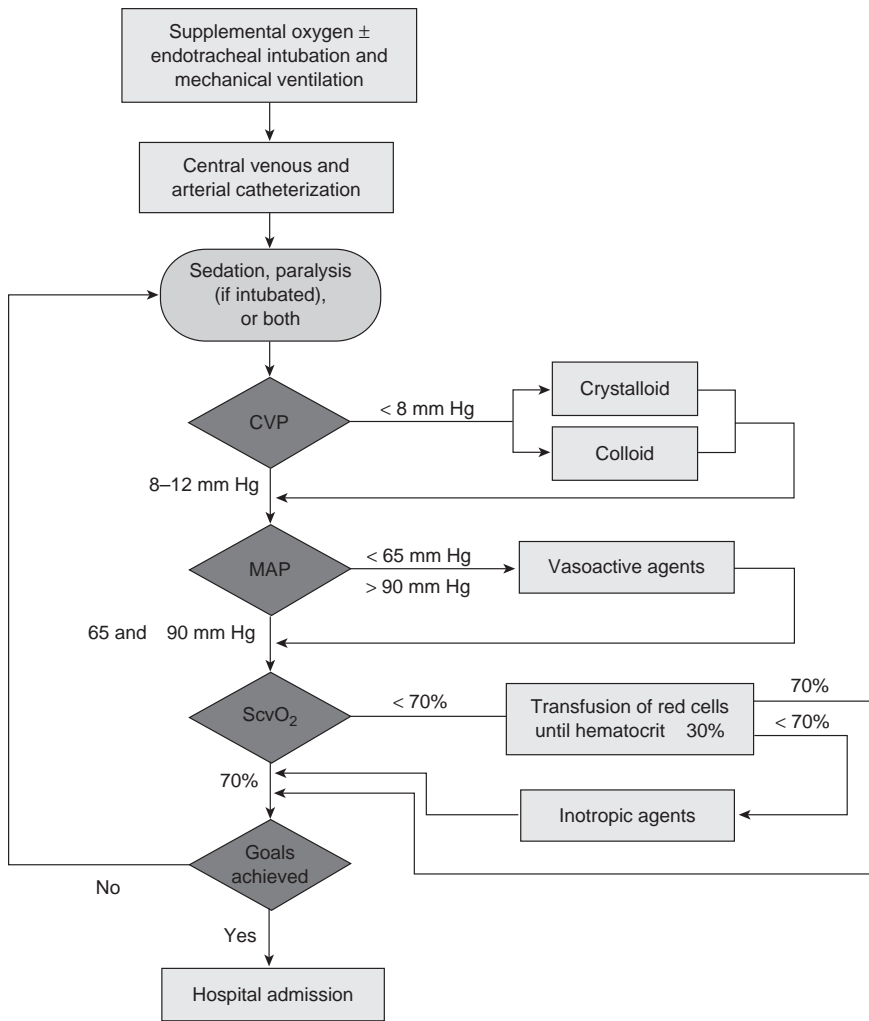
Figure 29.6 Protocol for Early Goal-Directed Therapy. (16) CVP denotes central venous pressure, MAP mean arterial pressure, and ScVO$_2$ central venous oxygen saturation.

Table 29.12 Vasopressors and inotropes used in shock states.

Vasopressors and Inotropes				
Drug	Receptors	CO	SVR	Dosing(mcg/kg/min)
Epinephrine	α1 ,β1, (β2)	↑↑	↑	0.02–0.5
Norepinephrine	α1, β1	↑	↑↑↑	0.02–0.3
Phenylephrine	α1	- - -	↑↑↑	40–300 mcg/min
Dopamine	β2, DR, (α)	↑	↑	2–20
Dobutamine	β1, β2	↑↑	↑	2–20
Vasopressin	Angiotensin III	↓	↑↑↑	5–20
Milrinone	PDI	↑↑	↓↓	0.25–0.75

Once the decision has been made to use vasopressor therapy, a vasopressor agent must be chosen. (Table 29.12) Some studies propose that norepinephrine and dopamine are better suited for patients in septic shock over epinephrine in that they have less potential for tachycardia and less vasoconstrictive effects on splanchnic circulation. However, it should also be noted that there is no definitive clinical evidence that epinephrine administration is associated with worse outcomes.(12)

In comparison to the adrenergic agent phenylephrine, norepinephrine, and dopamine are less prone to decrease stroke volume, but phenylephrine is least likely to produce tachycardia.

Dopamine has vasoconstrictive and ionotropic properties which produce increases MAP and cardiac output, primarily due to an increase in stroke volume and heart rate. Because of its ionotropic properties, it may be beneficial in patients with poor heart function. In contrast, norepinephrine is more potent than dopamine and increases blood pressure via vasoconstriction with only a minimal effect on heart rate and stroke volume.

If a MAP of > 65 mmHg cannot be maintained norepinephrine or dopamine, epinephrine should be administered as the first alternative agent.(12) Epinephrine, phenylephrine, or vasopressin is recommended as the initial vasopressor for septic shock, however, vasopressin 0.03 units/min may be added to norepinephrine.(69–72]

Vasopressin is commonly used as an adjunct to catecholamine vasopressor to support blood pressure in refractory septic shock and its use in this capacity is supported by the Surviving Sepsis Guidelines.(12) Vasopressin levels in septic shock patients have been found to be significantly lower than normal circulating levels of vasopressin (69–72), and there is some evidence to suggest administration of vasopression may have positive benefits in septic shock.(73) In the VASST trial, Russel and colleagues set out to evaluate if low-dose vasopressin as compared with norepinephrine would decrease mortality among patients with septic shock who were already being treated with conventional vasopressors. The multicenter trial randomized 778 patients to either

receive vasopressin or norepinephrine in addition to open-label vasopressors. They found no significant difference between the vasopressin and norepinephrine groups in either 28-day or 90-day mortality rates.(74)

WHAT ARE THE APPROPRIATE END POINTS OF RESUSCITATION?

Traditional end points of resuscitation have included easily observable measurements including blood pressure, heart rate, cognitive function, urine output, and subjective skin perfusion. Although useful in the initial recognition of shock, these parameters may not adequately identify ongoing, compensated shock. Deciding which factors are most appropriate end points of resuscitation is challenging, and optimal end points of resuscitation would predict a favorable outcome.(75–76) The hallmark of septic shock is severe vasodilatation, manifested by a low diastolic blood pressure, and a wide pulse pressure (SBP-DBP). Recent studies suggest that normalization of diastolic blood pressure and vascular tone in septic shock is an independent positive predictive factor of short term outcome. (77) Early lactate clearance is associated with improved outcome in severe sepsis and septic shock. In a recent prospective observational study, there was approximately an 11% decreased likelihood of mortality for each 10% increase in lactate clearance. Lactate clearance early in the hospital course may indicate a resolution of global tissue hypoxia and is associated with decreased mortality rate.(78) Recently published observational studies have demonstrated an association between maintenance of MAP > 65 mmHg and central venous oxygen saturation (ScVO$_2$, measured in superior vena cava, either intermittently or continuously) of ≥ 70% and improved clinical outcome in septic shock.(79–82) The optimal end point of resuscitation in severe sepsis and septic shock has not yet been determined and warrants further investigation.

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30 Perioperative management of a patient undergoing noncardiac surgery
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A 65-year-old male with a history of hypertension, controlled with a calcium channel blocker is scheduled for an open repair of a 6 cm asymptomatic infrarenal abdominal aortic aneurysm.

WHAT PERIOPERATIVE CARDIAC WORKUP SHOULD THE PATIENT UNDERGO?

Patients who are undergoing evaluation for abdominal aortic aneurysm surgery have the highest incidence of surgically correctable coronary artery lesions when compared to other patients undergoing noncardiac surgery.(1) In this study of 1,000 consecutive patients undergoing operations for peripheral vascular disease underwent preoperative cardiac catheterizations. This study noted that only 8% of the patients had normal coronary arteries and approximately one-third had severe correctable or severe inoperable coronary artery disease (CAD). CAD has the potential for causing severe perioperative morbidity and significant mortality, thus preoperative risk assessment is warranted so that a patient's status can be optimized and the risks minimized.

The steps below will take this patient through the algorithm from the 2007 ACC/AHA guidelines for patients undergoing noncardiac surgery. These guidelines take into account the timing of the surgery, active conditions, the patient's functional capacity, clinical risk factors, and type of surgical procedure. (2) These recent ACC/AHA guidelines have replaced the intermediate risk stratification category with the clinical risk factors from the Revised Cardiac Risk Index, with the exclusion of the type of surgery.(3) This index uses six independent risk correlates: ischemic heart disease (history of myocardial infarction (MI), history of a positive treadmill test, use of nitroglycerine, current complaints of chest pain due to coronary ischemia, or ECG with abnormal Q waves); congestive heart failure (history of heart failure, pulmonary edema, paroxysmal nocturnal dyspnea, peripheral edema, bilateral rales, S3 or chest radiograph with pulmonary vascular redistribution); cerebrovascular disease (history of transient ischemic attack or stroke); high-risk surgery (abdominal aortic aneurysm or other vascular, thoracic, abdominal, or orthopedic surgery); preoperative insulin treatment for diabetes mellitus; and preoperative creatinine greater than 2 mg/dL. Increasing risk factors with this index correlates to increased risk of perioperative cardiac events.

Step 1: Timing of the operation: Emergency versus urgent or elective surgery. Since this is an elective operation there is time for preoperative cardiac evaluation and assessment of postoperative risk. **Step 2**: Does the patient have one or more of the active conditions listed in Table 30.1. He has a history of hypertension that has been well controlled with a calcium channel blocker. He denies a history of an MI, angina, nitroglycerine use, diabetes

mellitus, or renal dysfunction. Further questions reveal no symptoms of decompensated heart failure such as orthostatic or paroxysmal nocturnal dyspnea. His physical examination reveals no cardiac murmur and no S3 or rales. He has a palpable 6 cm AAA and palpable distal pulses without evidence of edema. His chest X-ray shows no evidence of pulmonary edema and his ECG shows no evidence of a block, bradycardia, supraventricular, or ventricular arrhythmia. Given his lack of an active condition the evaluation should proceed to Step 3. **Step 3**: Is the patient undergoing low-risk surgery? An open abdominal aneurysm repair is a vascular procedure with a reported cardiac risk of often more than 5% and would *not* be considered a low-risk surgery. **Step 4**: Does the patient have a good functional capacity? Functional capacity is measured with metabolic equivalence (MET), which is the oxygen consumption of a 70-kg person in a resting state. Excellent functional capacity is a patient who can perform exercises requiring more than 7 MET or perform activities such as swimming, tennis, or jogging. A good functional capacity (4 MET or greater) without symptoms would involve climbing a flight of stairs or walking on level ground at 4 mph. This patient can walk a block or two, do activities of daily living but he does not walk up stairs, play sports, or do heavy lifting. Thus his functional capacity is unknown or poor.(4, 5) **Step 5**: If the patient has poor functional capacity, is symptomatic, or has unknown functional capacity, then the presence of active clinical risk factors will determine the need for further evaluation. Given that this patient has poor or unknown functional capacity, further evaluation of risk factors including ischemic heart disease, compensated or prior heart failure, diabetes mellitus, renal insufficiency, and cerebrovascular disease needs to be performed. Laboratory studies reveal he has an elevated creatinine to 2.1 mg/dL and an elevated fasting glucose and HbA1c, consistent with chronic renal insufficiency and diabetes mellitus. Thus this patient now has two clinical risk factors. Given the combination of two risk factors and proposed vascular surgery, the guidelines recommend that he may undergo the planned surgery with heart rate control with a beta blocker or consider noninvasive testing if the latter will change management. In his case it may change management, causing one to consider different approach to his repair; thus, noninvasive testing should be considered. A final important note, if patients have three or more risk factors, the surgery-specific cardiac risk is important. Major vascular surgery represents the highest risk procedures and thus in this latter scenario, noninvasive testing should be considered.(6, 7)

WHAT NONINVASIVE CARDIAC EVALUATION SHOULD BE PERFORMED?

The patient should first have an ECG. If he does not have a left bundle branch block, left ventricular hypertrophy, pre-excitation syndrome, electronically paced ventricular rhythm, resting ST depression greater than 1 mm or digitalis effect on ECG and he can ambulate on a flat surface, an exercise ECG is chosen for

Table 30.1 Active Condition Which Should Prompt.

Evaluation and Treatment before Noncardiac Surgery
Unstable Coronary Syndromes or Angina
Unstable or Severe Angina
Recent MI
Decompensated Heart Failure (HF)
New York Heart Association (NYHA) functional class IV; worsening or new onset HF
Significant Arrhythmias
High-Grade Atrial Ventricular (AV) block
Mobitz II AV block
Third-degree atrioventricular heart block
Symptomatic ventricular arrhythmias
Supraventricular arrhythmias (including atrial fibrillation) with uncontrolled ventricular rate (over 100 beats per minute at rest)
Symptomatic bradycardia
New diagnosis ventricular tachycardia
Severe Valvular Disease
Severe aortic stenosis (mean pressure gradient greater than 40 mmHg, aortic valve area less than 1.0 cm^2 or symptomatic)
Symptomatic mitral stenosis (progressive dyspnea on exertion, exertional presyncope or heart failure)

Source: Ref(2).

noninvasive testing. Therre (8), in a study of preoperative testing prior to AAA repair, reported 38 of 70 patients (54%) in whom ET was feasible and who were able to achieve the minimum HR; the specificity of ET was excellent (95.8%), and the sensitivity was 71.4% when compared to coronary angiography. However, these 38 patients accounted for only 42% of the patients in the series. The majority of patients were unable to complete an exercise ECG. Those who were unable to complete ET underwent dobutamine stress echocardiography with a sensitivity of 78%, specificity of 75.5%, and diagnostic accuracy of 100% when compared to coronary angiography. Pharmacological stress with vasodilators or adrenergic stimulation in conjunction with radionuclide or echocardiographic imaging has been shown in a meta-analysis of 68 studies to predict perioperative cardiac events in patients scheduled for noncardiac surgery who are unable to exercise. The cardiac risk by this evaluation is related to the extent of jeopardized viable myocardium identified by stress cardiac imaging.(9)

Resting LV function by echocardiography, radionuclide angiography, or contrast ventriculography has not been found to be a consistent predictor of perioperative ischemic events.(2)

Finally, if noninvasive test results are positive or non-diagnostic in a patient who is intermediate clinical risk and undergoing a high-risk noncardiac surgery is positive, the patient should undergo coronary angiography.(10)

SHOULD THE PATIENT RECEIVE PRE-, INTRA- AND/OR POSTOPERATIVE BETA-BLOCKERS? WHEN SHOULD THESE START AND WHEN SHOULD THEY BE DISCONTINUED?

Current guideline committees and multiple authors recommend that in the absence of contraindications, beta blocker therapy should be considered for all patients at high risk for coronary events who are scheduled to undergo noncardiac surgery.(2, 10–13) Whenever possible, this treatment should be initiated prior to surgery to achieve effective beta blockade with a resting heart rate goal of 50–60 beats per minute and maintaining an intraoperative and postoperative heart rate of less than 80 beats per minute. The beta blocker should be continued several weeks postoperatively. However, the two randomized controlled trials leading to these recommendations have limitations that have led to controversy and reconsideration. The Poldermans (14) trial of 112 patients with positive results on dobutamine echocardiogram were started on oral bisoprolol at least 1 week before surgery and continued on oral bisoprolol or intravenous metoprolol for 30 days postoperatively. The trial was stopped after an interim analysis based on 20 outcome measures which demonstrated a relative risk reduction of 90% in the composite outcome of cardiac death and nonfatal MI. The relative risk reduction for nonfatal MI alone was 100%. Critics of the results of this study for global treatment recommendations point out that the study was not blinded, had unclear randomization strategies, selected a very high-risk population, and the study was stopped early.(15) The second trial, by Mangano (16), included 200 patients with known CAD or two minor risk factors for CAD. Patients were started an atenolol orally or intravenously 30 minutes before surgery and continued postoperative for 7 days. The overall mortality after discharge from the hospital was significantly lower among the atenolol-treated patients. However, the improvement in all cause mortality in this study was no longer statistically significant when patients who died while receiving the study drug were included in the intention to treat analysis. Two recent trials have not shown benefit from beta-blocker therapy (17, 18) but, due to a low number of patients and thus underpowered; these studies have been unable to determine the impact of beta blocker therapy on major cardiovascular outcomes. A recent meta-analysis of eight randomized studies reporting acute perioperative beta blockade, major perioperative cardiovascular outcomes and noncardiac surgery failed to confirm that heart rate control is cardioprotective.(15)

To add to the controversy, at the November 2007, American Heart Association Scientific Sessions, Devereaux et al.(19) presented the results of the PeriOperative Ischemic Evaluation (POISE) trial. The trial had enrolled 8,351 patients to determine the impact of the beta blocker metoprolol on the 30-day risk of major cardiovascular events in noncardiac surgery patients. Patients received an oral dose of 100 mg controlled-release metoprolol or placebo 2–4 h before surgery and between 0 and 6 h after surgery. Twelve hours following the first postoperative dose, patients started taking either daily doses of metoprolol or placebo at 200 mg and continued for 30 days after surgery or 15 mg of the drug or normal saline as a placebo intravenously every 6 h until patients were ready to switch back to oral doses. Like prior studies (17, 18), the POISE data showed that metoprolol was associated with an increased incidence of significant hypotension (15.0% vs. 9.7%; $p < 0.0001$) and significant bradycardia (6.6% vs. 2.4%; $p < 0.0001$). The primary end point was a composite of cardiovascular death, nonfatal MI, and nonfatal cardiac arrests at 30 days. A composite end point reduction was primarily due to a reduction in nonfatal MIs, with a hazard ratio of 0.7, equal to a 30% reduction in the risk of nonfatal MIs among those patients given beta-blockers

versus placebo prior to noncardiac surgery. However, total mortality and the incidence of stroke were significantly increased in the metoprolol group. Thus, the evidence of this yet to be published study suggests that a beta-blocker will decrease the likelihood of a perioperative MI but at the same time increase the risk of stroke and death.

At the time of the writing of this chapter, the current ACC/AHA guidelines for cardiovascular evaluation of patients undergoing noncardiac surgery recommend that if the patient has clinical risk factors, if appropriate, the patient should receive perioperative beta-blockers titrated to a resting heart rate of 50–60 beats per minute with the aim of maintaining an intraoperative and a postoperative heart rate of less than 80 beats per minute.

SHOULD THE PATIENT BE PLACED ON A 3-HYDROXY-3-METHYL-GLUTARYL-COA REDUCTASE INHIBITOR (STATIN) PREOPERATIVELY?

Statins have emerged as promising cardioprotective drugs in the primary prevention of cardiac events in patients undergoing vascular surgery.(20, 21) The ACC/AHA guidelines have not yet endorsed perioperative statin therapy due to the lack of prospective data. One study has suggested that statins are associated with a decreased incidence of perioperative mortality and nonfatal myocardial infarction after aneurysm repair.(22) A more recent prospective study of 359 vascular surgery patients revealed that higher statin doses and lower LDL cholesterol levels were both associated with a lower incidence of perioperative myocardial ischemia by continuous 12 lead electrocardiographic monitoring, perioperative troponin T release, and 30 day and late cardiac events.(23) More studies, however, need to be performed to clarify patient selection, dosage, duration of therapy preoperative, and to standardize outcome measures.

WHAT INTRAOPERATIVE EVENTS INCREASE THE RISK OF SILENT MI?

Adverse cardiac events have been attributed to excessive stress on the myocardium caused by the combined effect of anesthetic induction, aortic cross clamping and declamping, operative blood loss, and associated hemodynamic and metabolic changes. The classic signs of intraoperative cardiac dysfunction of ischemia are dysrythmia, hypotension, hypoxia, decreased urinary output, and ST changes including depression and elevation. However, ischemia can be more subtle and only noted with close monitoring of ST segment analysis and intraoperative transesophageal echocardiography.

The initial response to clamping the aorta is arterial hypertension due to impedance of aortic flow with no significant effect on heart rate. Infrarenal clamping can increase blood pressure 7 to 10% with an increase in both preload and afterload. The effect on cardiac filling pressures is variable and cardiac output can be decreased by 9 to 33%.(24). Infrarenal clamping is often well-tolerated in patients with preserved ventricular function but, in the presence of significant dysfunction, it can precipitate ischemia and heart failure.(25)

Ischemia may be monitored with I-II-V5/6 ST segment electrocardiographic analysis and left ventricular wall imaging by transesophageal echocardiography. Simultaneously viewing leads II and V5 provides an 80% sensitivity for detecting intraoperative myocardial ischemia since most ischemia occurs inferior and lateral. Sensitivity has been shown to be improved with simultaneously viewing V4 and V5. Studies comparing ECG with wall motion abnormalities seen on transesophageal echocardiography (TEE) report ECG may miss 40 to 75% of intraoperative ischemic events.(26) Intraoperative myocardial ischemia in this study is defined as ST-segment depression of 0.5 mm or more or ST-segment elevation of 2 mm or more in the precordial leads and 1 mm or more in all other leads, compared with the baseline reading and lasting for at least 1 minute. Ischemic findings on TEE are defined as decreased ventricular wall thickness during systole or segmental regional wall motion abnormalities of two or greater in wall motion score in one or more of the 13 segments of the left ventricle.(27)

WHEN/WHY DO PERIOPERATIVE MI'S OCCUR?

Based on retrospective studies in the 1980s and 1990s which evaluated autopsy records of patients who had fatal MI's following elective or emergent noncardiac surgery it was hypothesized that the etiology of the MI was secondary to acute plaque rupture and coronary thrombosis similar to non-surgical MI patients. (28, 29) More recently there is growing data that an early perioperative MI, in the setting of CAD, may be related to prolonged imbalance between myocardial oxygen supply and demand. In high-risk patients undergoing vascular surgery who had electrocardiographic monitoring postoperatively (30), the majority of ischemic events (67 %) including those culminating in MI, were reported to start between 50 minutes before and 60 minutes after the end of surgery and during the emergence from anesthesia. This time is characterized by an increase in heart rate, blood pressure, and sympathetic discharge.(31) This early postoperative incidence is supported by studies of patients with significant troponin elevation without ST-segment elevation or Q wave MI and by studies in patients with perioperative MIs who have coronary angiography that reveal severe CAD without thrombus or ulcerated plaques (30) and corresponds to the peak incidence of prolonged, stress induced, ST depression type of MI. The mechanism appears that a significant decrease in coronary and myocardial blood flow may be occurring secondary to tachycardia, hypotension, vasoconstriction, shortened diastolic time, and fixed stenosis secondary to CAD.

In the past 15 years, several studies report that the rate of perioperative MI has ranged from 0 to 7% and fatal MI has ranged from 0 to 5% after open aortic surgery. Pooled results suggest that only 14 % of patients experiencing a perioperative MI will have chest pain and only 53% will have a clinical sign or symptom that may trigger a physician to consider an MI.(32) The majority of postoperative myocardial infarctions occur during the first 3 days after surgery (33, 34), a period in which most patients receive analgesics, may remain intubated and sedated or have symptoms of hypotension, tachycardia, nausea, or shortness of breath, which may be attributed to other postoperative complications. Inflammation may contribute to fluid shifts, hypercoagulable states, multisystem organ dysfunction, and release of

proinflammatory cytokines which affect vascular function and endothelium-derived factors involved in blood pressure regulation. Thus the onset of postoperative inflammatory reaction may play a role in the occurrence of the later postoperative MI.

A late cause of postoperative MI has been attributed to rebound in rapid eye movement sleep in patients receiving opioids that may cause sleep apnea-induced arterial oxygen desaturation which has been shown to be associated with myocardial ischemia.(35)

WHAT IS THE APPROPRIATE PERIOPERATIVE SURVEILLANCE?

The current recommendation for -low risk patients undergoing low-risk procedures is no perioperative surveillance for acute coronary syndromes with routine ECG and cardiac serum biomarkers.(2) However, in patients with known or suspected CAD, an ECG should be performed at baseline, immediately postoperative and on the first 2 days after surgery.(36)

There are differing opinions regarding obtaining biomarkers such as creatinine kinase- MB, and troponin in high-risk patients. Mukherjee and Eagle (37) recommend creatine phosphokinase-MB (CPK-MB) and troponin measurements in high-risk patients immediately postoperative and the following day. Other authors recommend the use of troponin only because perioperative creatine phosphokinase-MB (CK-MB) measurements are prone to false-positive and false-negative values. The former resulted from the release of CK-MB from skeletal muscle following surgical trauma.(38–40)

Finally, the American College of Cardiology/American Heart Association (ACC/AHA) guidelines (2) state that surveillance should be restricted to those patients who develop perioperative signs of cardiovascular dysfunction and that routine measurement of troponin after surgery is more likely to identify patients without acute MI than with a MI. Studies of troponin elevations neither consistently show associations with adverse cardiovascular outcomes at any time point nor provide insight into the effect of treatment on outcomes in patients with an elevated troponin. Troponin levels do correlate with more extensive CAD; however, the role of revascularization in patients with an elevated troponin level but no other manifestation of MI remains unclear. Thus until these issues are clarified routine troponin measurement is not recommended.(2)

WHAT IS THE SIGNIFICANCE OF POSTOPERATIVE ELEVATION OF CARDIAC ENZYMES WITH NO ECG CHANGES?

As stated in the above question the ACC/AHA guidelines restrict surveillance to those only with signs of cardiovascular dysfunction. The ACC/AHA guidelines (2) state that surveillance should be restricted to those patients who develop perioperative signs of cardiovascular dysfunction and that routine measurement of troponin after surgery is more likely to identify patients without acute MI than with MI. Studies of troponin elevations neither consistently show associations with adverse cardiovascular outcomes at any time point nor provide insight into the effect of treatment on outcomes in patients with an elevated troponin. Troponin levels do correlate with more extensive CAD; however, the role of revascularization in patients with an elevated troponin

level, but no other manifestation of myocardial ischemia such as ST changes remains unclear. Reiterated from the previous question regarding surveillance, until these issues are clarified routine troponin measurement is not recommended.(2)

WHAT IS THE CRITERION FOR DIAGNOSIS OF A PERIOPERATIVE MI?

The definition of an MI formulated by the European Society of Cardiology and the American College of Cardiology in a consensus document and the diagnostic criterion of a perioperative MI which is currently being used in the POISE trial is similar. The diagnosis requires one of the following: Criterion 1—A typical rise in troponin level or typical fall of an elevated troponin level or a rapid increase and decrease of creatine kinase (CK)-MB. An increased troponin value is a measurement exceeding the threshold at which the coefficient of variation equals 10%. An increased CK-MB value is one that exceeds the 99th percentile for CK-MB values in a reference control group. This criterion requires that one of the following criteria must also exist: ischemic signs or symptoms, development of pathological Q waves on ECG, ECG changes indicative of ischemia, coronary artery intervention or new cardiac wall motion abnormality on echocardiography, or new fixed defect on radionuclide imaging. Criterion 2—Pathological findings of an acute or healing MI. Criterion 3—Development of new pathological Q waves on an ECG if troponin levels were not obtained or were obtained at times that could have missed the clinical event.(19, 41)

This POISE study (19) recommends that if clinicians wish to avoid missing a significant proportion of perioperative MI and identify high risk of intermediate or long-term major cardiac events, they should consider monitoring troponin levels and ECG daily during the first 3 days after surgery. However, choosing who to monitor is not definitively recommended until further studies are done. Potential candidates for this protocol would include patients with established atherosclerotic disease requiring postoperative admission or patients with risk factors for perioperative events such as diabetes mellitus, renal insufficiency and history of heart failure, or cerebrovascular disease.

HOW SHOULD PERIOPERATIVE MI'S BE TREATED? IS THIS PATIENT A CANDIDATE FOR A CARDIAC STENT?

The treatment of an ST elevation myocardial infarction (STEMI) in the postoperative period, especially major open vascular surgery, is complicated by the risk of hemorrhage with the agents used in management of STEMI's. The guidelines for treatment for STEMI should be followed. Administration of oxygen to correct hypoxia is the initial step. Nitrates, analgesics, and beta-blockers should be used if blood pressure/perfusion pressure and heart rate allows. Aspirin (162 mg or more) should be highly considered even in the postoperative period and has been demonstrated in the ISIS-2 trial (42) to be comparable to streptokinase in mortality reduction. Strategies for implementation of reperfusion in the early postoperative period are more problematic. The use of heparin to reduce the risk of mural thrombus must be evaluated from a risk–benefit standpoint, including location of

the MI (anterior versus lateral) and the risk of hemorrhage in the operative site and the etiology of the MI (plaque rupture, thrombosis, hypoxemia, or inflammatory response). Up to two-thirds of patients with STEMI are not candidates for thrombolysis due to contraindications. The early postoperative period (within 3 weeks) is a relative to absolute contraindication to thrombolytic therapy. The risk of bleeding favors the use of percutaneous coronary intervention (PCI) over thrombolytic therapy, if it is available.

Acute coronary reperfusion can be accomplished by balloon angioplasty and is an acceptable alternative to thrombolysis. PCI should be considered when thrombolysis is contraindicated. Multiple randomized trials have suggested that primary PCI is superior to fibrinolytic therapy in reducing the rates of death, reinfarction, intracranial bleeding, and recurrent ischemia when timely performed in experienced centers.(43–46) The absolute difference in mortality at 30 days between PCI and fibrinolysis increases in favor of PCI as the estimated risk of mortality with fibrinolysis increases.(47) The most benefit in mortality with PCI are in those patients with an anterior STEMI and those patients at the highest risk and those in cardiogenic shock.(48) The Management of Patients with STEMI: Executive Summary (49) recommends that primary PCI should be performed in patients with STEMI or MI with new or presumably new LBBB, if performed within 12 h of symptom onset and within 90 minutes of presentation by skilled personnel. This includes patients who are ineligible for fibrinolytic therapy. It is difficult to find studies or even case reports of patients undergoing treatment of early postoperative STEMIs following noncardiac surgery. However, there are reports of post-trauma patients treated with PCI following blunt and penetrating force injuries. O'Neil (50) reported a case of successful PCI in a patient who suffered an evolving STEMI and cardiogenic shock within hours of presentation of a hemothorax, a pulmonary contusion and femur fracture from multiple gunshot wounds.

Placement of coronary stents may also be considered in the postoperative patient. In a review of nine studies, the STEMI: Executive Summary noted no differences in mortality or reinfarction rates when comparing primary stenting with primary angioplasty.(49) The major adverse cardiac events, however, were reduced by stenting, driven by the reduction in subsequent target vessel revascularization with stenting. Thus this may be considered if anatomy favors this technique. However, again one must consider the risk of antiplatelet or glycoprotein IIbIIIa inhibiting agents associated with this procedure.

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31 Postoperative cardiac arrythmias
Scott C Brakenridge and Joseph P Minei

Case #1 – A 54-year-old male with a significant past medical history of non-insulin-dependent diabetes mellitus well controlled with oral hypoglycemics is admitted to the Surgical Intensive Care Unit (SICU) after an elective tranhiatal esophagectomy for esophageal carcinoma. During the 4-h procedure, the patient received 2 units packed red blood cells and 4 L or litres of crystalloid solution. He was extubated without incident in the recovery room and transferred to the intensive care unit for postoperative monitoring. During the fourth postoperative hour the patient develops a narrow complex tachycardia with a heart rate of 150 beats/min. He is awake, alert, and complains only of mild incisional pain. His blood pressure remains stable at 140/80 mmHg. Twelve-lead EKG reveals the rhythm as atrial fibrillation.

POSTOPERATIVE ATRIAL FIBRILLATION—OVERVIEW

Atrial fibrillation (AF) is the most common significant postoperative arrhythmia after any surgical procedure. The incidence, however, varies significantly depending on the type of surgical procedure performed. Postoperative AF complicates from 3 to 8% of non-cardiac surgeries.(1–3) The incidence of AF in thoracic and cardiac procedures is significantly higher. In non-cardiac thoracic surgeries the incidence ranges from 3% for wedge resection, 13% for esophagectomy, and as high as 33% for lobectomy.(4) After cardiac surgery, the rate is as high as 16–46% with the highest rates found in valvular procedures.(2, 5–7) Onset of the arrhythmia usually appears between the second and the fourth postoperative day. Postoperative arrhythmias of all types are most likely to occur in patients with pre-existing structural heart disease, even if the patient has not had a previous occurrence. It is thought that this abnormal cardiac substrate is predisposed to arrhythmia, which is subsequently triggered by the physiologic stress of the perioperative period. These perturbations include hypoxemia, hypercarbia, excess endogenous catecholamines, electrolyte imbalances, acute atrial distention from volume overload, systemic inflammation, or in the case of cardiac surgery, direct cardiac trauma and the resultant local inflammatory response.(1, 2)

The epidemiologic risk factors for postoperative AF have been well defined. For both cardiac and non-cardiothoracic surgeries the single most predictive risk factor for onset of AF in the perioperative period is patient age.(2) It is hypothesized that preexisting age-related changes in the atrial myocardium explain this increase in risk. Preoperative risk factors specifically for cardiac surgery patients include congestive heart failure (CHF) with ejection fraction < 35%, chronic obstructive pulmonary disease, obesity, and male gender.(2) Intraoperative factors have also been shown to predispose to onset of postoperative AF including on-pump cardiopulmonary bypass, valvular surgery, prolonged use of perioperative inotropes, increased aortic cross clamp time, and net perioperative fluid balance.(2, 8) The risk factors for development of AF after non-cardiac surgery have not been as extensively investigated. However, similarly to cardiac patients, male gender, pre-existing cardiac conditions (CHF, valvular disease), and asthma have been described as predictive risk factors.(3, 4) Operative risk factors shown during non-cardiac surgeries include pulmonary resection, intra-abdominal, intrathoracic, or major vascular procedures.(3)

For those patients in the ICU, AF is most commonly diagnosed by an abnormal rhythm on cardiac monitoring. Patients on the ward most often present with palpitations or an abnormally high or irregular heart rate. Diagnosis is confirmed by 12-lead electrocardiogram. While often presenting in a benign fashion and typically transient and reversible, the concern for postoperative AF arises from its association with greater morbidity and mortality, longer length of stay and higher postoperative costs which have been confirmed across multiple studies.(2, 3, 6, 7, 9, 10) It is not clear whether these outcomes are actually a consequence of the arrhythmia itself or whether AF is just a marker for a more fragile patient with underlying heart disease.

WHAT SHOULD BE DONE IF THE PATIENT'S BLOOD PRESSURE IS 80/40?

The urgency of treatment of acute-onset AF depends on the physician's clinical assessment of the patient's status. AF can result in poor diastolic filling with subsequent decrease of cardiac output and potential hemodynamic instability. While a decreased blood pressure alone may not warrant emergent therapy, hypotension with signs of decreased perfusion including altered mental status, loss of consciousness, hemodynamic instability, or evidence of ongoing ischemia warrant immediate intervention. Synchronized electrical cardioversion should be performed as per American Heart Association Advanced Cardiac Life Support guidelines. (1, 11) If possible, the conscious patient should be pre-medicated with an intravenous benzodiazepine and/or opiate.

Given the patient remained asymptomatic and hemodynamically stable, immediate cardioversion was not indicated in this case.

HOW SHOULD THIS EPISODE BE TREATED?

Acute management of postoperative AF focuses on ventricular rate control, pharmacologic, or electrical rhythm cardioversion to restore normal sinus rhythm, and identification of any correctable, inciting underlying physiologic derangements. All pharmacologic interventions for rate control in AF exert their effect by prolonging conduction in the AV node. Intravenous β-receptor antagonists (β-blockers) are the preferred agents for rate control in patients with high sympathetic tone, such as in the postoperative patient.(12–14) Esmolol is preferred to metolprolol due to its extremely short half-life (9 min.) which allows rapid and easily controllable titration to effect. The calcium-channel blocker diltiazem is another acceptable

option and is commonly the agent of choice in medical patients with acute-onset AF. Due to the negative inotropic effects of both agents their concomitant usage should be avoided. Amiodarone is another useful drug in the treatment of acute AF in the critically ill patient. While not quite as effective at achieving adequate heart rate reduction as diltiazem (75% as opposed to 85%), amiodarone has less cardiodepressive effects making it useful in the hemodynamically unstable patient or when β-blockers or calcium-channel blockers are not tolerated.(15) Digoxin, while commonly used for rate control in chronic AF, is rarely effective for rate control in acute AF secondary to its slow onset of action.

If possible, cardioversion to sinus rhythm is optimal after rate control is achieved. If cardioversion is attempted within 48 h of onset of the arrhythmia, anticoagulation is not required as risk of an embolic event is less than 1%.(12) As previously mentioned, electrical cardioversion is usually reserved for those patients with hemodynamic compromise. The most effective pharmacologic agent for acute cardioversion is ibutilide (1 mg IV bolus over 10 minutes may repeat × 1) which has a 50% conversion rate, within approximately 30 minutes of administration.(16) Vigilant monitoring is required as torsade de pointes is a rare but significant complication secondary to QT prolongation. Spontaneous cardioversion can occur after bolus administration of amiodarone making it an attractive option for concurrent cardioversion and rate control. Its effectiveness is limited, however, with acute conversion to sinus rhythm in less than 5% of patients.(17)

Identification and correction of any underlying physiological derangements common in the perioperative period that may have triggered the episode is required. Careful attention should be given to postoperative electrolyte monitoring and correction. Volume status should be carefully assessed with consideration of gentle diuresis if volume overload is suspected.

> Initial rate control was obtained with an intravenous esmolol drip which was titrated to keep the patient's heart rate <100 bpm. The patient's potassium was found to be 2.8 mmol/L, which was carefully repleted intravenously. A subclavian central venous catheter had been placed prior to the case which revealed a central venous pressure of 18 cm H20. Gentle diuresis was performed using intermittent bolus IV furosemide. The patient spontaneously reverted to sinus rhythm the morning of postoperative day 1.

WHAT PATIENTS SHOULD RECEIVE PRE-AND/OR INTRAOPERATIVE PROPHYLAXIS FOR AF?

Due to the demonstrated impact of postoperative AF on morbidity and mortality, its prevention has been an area of aggressive investigation. This is especially true in the realm of cardiac surgery patients, from which most of the current data have been obtained. The use of perioperative β-blocking agents, sotalol, amiodarone, and magnesium sulfate have been shown to significantly reduce the incidence of supraventricular arrhythmias after cardiac and general thoracic surgery.(2) However, no significant decrease in postoperative morbidity, mortality, or length of stay have been consistently shown across these studies. Recently, the HMG-CoA reductase inhibitor ("statin") class of agents has shown some potential for

AF prophylasis. Several observational studies and one prospective randomized controlled trial have shown a decrease in incidence of AF with perioperative administration of statin agents.(2, 18) While promising, further investigation is required to fully determine their utility as a prophylactic agent for postoperative AF.

The current American College of Cardiology/American Heart Association/European Society of Cardiology (ACC/AHA/ESC) guidelines recommend β-blockers as first-line agents for the prevention of postoperative AF following cardiac surgery. Amiodarone and sotalol are considered second tier, but acceptable alternatives.(12) Currently, there are no recommendations for AF prophylaxis following non-cardiac surgery. If tolerated, prompt reinstitution of β-blockers in those patients on these medications pre-operatively is reasonable and appropriate.

> Given that this patient was not previously on beta blockers and was not undergoing cardiac surgery he was not started on perioperative pharmacologic prophylaxis, as per current guidelines.

SHOULD SURGICAL PATIENTS WHO DEVELOP POSTOPERATIVE AF BE WORKED UP TO RULE OUT MYOCARDIAL INFARCTION? PULMONARY EMBOLUS? THYROTOXICOSIS?

Currently, it is common practice in many ICU's to evaluate for myocardial infarction (MI) and pulmonary embolus (PE) as a cause of postoperative arrhythmia. In general, AF is not specifically associated with underlying coronary artery disease. The exception to this is in the setting of an acute MI where 6–10% will have evidence of transient AF.(19–21) The incidence of acute MI in all patients presenting with acute AF, however, is low (2%) in the absence of other signs or symptoms.(22, 23) The diagnosis of MI in the post-surgical and ICU patient can present a diagnostic challenge because postoperative pain and sedation/intubation can preclude diagnosis using standard clinical predictors. Among non-cardiac surgery patients only 14% of patients have chest pain and 47% present without any signs or symptoms suggestive of myocardial ischemia.(24) Given these facts it is reasonable to rule out any postoperative patient who develops AF with EKG monitoring and serial troponin levels (q6 h × 3). This is especially true for patients with known significant perioperative cardiac risk factors, including diabetes, pre-existing renal insufficiency, and history of coronary artery disease, CHF, or stroke. The diagnosis of perioperative MI in the post-cardiac surgery patient is further complicated by the fact that cardiac enzyme elevations and EKG changes can occur as a result of the surgical procedure itself. Given the high incidence of AF in these patients, its onset in cardiac surgery patients is not predictive of MI. Often these patients are already on continuous monitoring with serial cardiac enzyme monitoring.

AF is seen in approximately 10–14% of patients with documented pulmonary embolism.(25, 26) However, it is rarely the only sign or symptom of acute PE. Without evidence of other signs or symptoms such as dyspnea, pleuritic chest pain, and hypoxia, workup of PE for onset of postoperative AF is not required.

Patients with hyperthyroidism and subclinical hyperthyroidism are associated with increased risk for the development of AF over

the course of their lifetime. Although this association has been shown across several studies, a definitive cause and effect relationship has not been established.(27, 28) While increased β-adrenergic tone is hypothesized as a possible cause of AF in hyperthyroidism, its relationship with postoperative AF is unknown. There is currently no evidence to support the workup of hyperthyroidism in the patient with postoperative AF. An outpatient evaluation for hyperthyroidism in a patient after an episode without any other identified precipitating factor may be reasonable.

> Initial 12-lead EKG revealed no evidence of ischemia associated with the ongoing AF. No subsequent changes were noted while the patient remained on standard cardiac monitoring. The patient was ruled out for MI with q6 h EKG and troponin levels × 3.

WHAT IS THE STROKE RISK WITH AF?

Although rare, embolic ischemic cerebrovascular events are the most devastating adverse events associated with acute-onset AF. Of all patients with AF the stroke rate ranges between 2 and 6% per year depending on associated risk factors. High-risk individuals include those with rheumatic valvular disease, prosthetic valves, history of previous thromboembolism, heart failure, or age > 75 years. Low-risk individuals are patients age < 60 years with no evidence or history of heart disease.(12) The risk of stroke specifically with postoperative AF has been most thoroughly described after cardiac surgery. The in-hospital stroke rate in these patients has been reported between 1.5 and 2.8% compared to 1.2% in patients without AF.(10, 13, 29)

WHAT IS THE ROLE FOR ANTICOAGULATION IN THESE PATIENTS?

The need for anticoagulation in patients with post-operative AF depends on the patient's underlying history and subsequent course of the arrhythmia. As mentioned previously, in patients with no previous history of arrhythmia, postoperative AF is most often self-limiting. Patients who spontaneously return to sinus rhythm or undergo successful cardioversion within 48 h of onset and are younger than 60 years with no evidence of heart disease or previous arrhythmia are classified as low risk of thromboembolism (< 1%) and do not require long-term anticoagulation. (12) When AF has been present greater than 48 h, anticoagulation for 3 weeks prior to attempted cardioversion is recommended as the risk of embolization rises to 6%.(12)

The decision for long-term oral anticoagulation in those with recurrent or refractory AF is based on the patient's risk classification as described previously. Although the yearly incidence of intracerebral hemorrhage is low with systemic oral anticoagulation (< 1%), the risks of bleeding complications must be weighed for each individual patient. According to ACC/AHA/ECC guidelines, it is recommended that patients classified as high risk should have systemic oral anticoagulation with warfarin to maintain an international normalized ratio (INR) of 2.0–3.0. Low-risk patients older than 60 years, or those younger than 60 years with heart disease, may be treated with anti-platelet therapy (aspirin, 325 mg daily). No therapy is required for patients age < 60 years without heart disease.(12)

> Given that this patient spontaneously converted to sinus rhythm less than 48 h from time of onset and is classified as low-risk for thromboembolism, anticoagulation was not required.
>
> Case#2 – A 20-year-old male riding a motorcycle without a helmet loses control on a rainy, wet road at 50 mph. He subsequently strikes a light pole and is thrown approximately 30 ft. At the scene he remains lucid but is unable to move his upper or lower extremities. Upon arrival to the Emergency Department his Glasgow Coma Score (GCS) is 15, he has no motor or sensory function below the base of his neck. His pulse rate and blood pressure on presentation are 42 and 85/50 mmHg, respectively. His trauma workup reveals a closed midshaft tibia fracture and a C5 burst fracture with significant retropulsion and cord compression. No pelvic fracture, abdominal, or chest injury is identified. The patient is transferred to the SICU where despite initial fluid resuscitation with 3 L or liters of crystalloid solution he remains bradycardic and hypotensive.

NEROROGENIC BRADYCARDIA/SHOCK—OVERVIEW

Neurogenic shock is a pathophysiologic state of abnormal global tissue perfusion secondary to decreased vasomotor tone with associated bradycardia and hypotension after high thoracic or cervical spinal cord injury (SCI). The term "spinal shock" is often used synonymously with neurogenic shock. In much of the literature of SCI physiology, however, the term spinal shock refers to the decreased neuronal activity distal to the level of injury and the hyporeflexive state of peripheral reflexes. Additionally, there is controversy within the field as to the definition of the clinical signs for resolution of spinal shock. This ranges from the appearance of the bulbocavernosus reflex within the first few days after injury to the return of bladder detrusor function which often takes months.(30) For these reasons, and given that the acute care surgeon is most concerned with the immediate cardiovascular function and perfusion status of the SCI patient, the term neurogenic shock should be used when referring to hemodynamic instability in these patients.

Following high thoracic or cervical SCI, the immediate compromise of motor and sensory function at or below the level of injury is often accompanied by hypotension without compensatory tachycardia and loss of peripheral vasomotor tone. This is a result of a transient shutdown of peripheral and autonomous neurologic activity which is thought to be caused by a lack of supraspinal excitatory and inhibitory inputs.(30) The normal balance of the autonomic nervous system is thought to become disrupted with sympathetic failure and an uncompensated parasympathetic response. While yet to be fully described in humans, multiple animal studies have shown that immediately after SCI there is a transient increase in sympathetic activity lasting for between 5 and 10 minutes, associated with a spike in heart rate and blood pressure.(31, 32) This response abates within approximately 20 minutes after which increased parasympathetic activity dominates.(33) This parasympathetic dominance leads to the

observed cardiovascular effects of decreased peripheral vascular resistance, bradycardia, and decreased cardiac output which ultimately manifest as hypotension and global malperfusion. While bradycardia is the most common occurring arrhythmia, others include AV blocks, AF, and sinus arrest longer than 3 seconds.(34) Asystole has been a reported event in approximately 15% of patients.(35, 36)

WHAT IS THE MOST APPROPRIATE MANAGEMENT OF THE PATIENT WITH SCI WHO IS BRADYCARDIC AND HYPOTENSIVE?

Despite adequate volume resuscitation, approximately 25–30% of patients with high thoracic and cervical cord injuries may not be able to maintain an adequate blood pressure due to the combination of decreased cardiac output secondary to bradycardia and decreased peripheral vascular resistance.(37) These patients require pharmacologic inotropic/chronotropic as well as vasopressive support to maintain adequate global tissue perfusion. The key to initial therapy is resuscitation to appropriate volume status, treatment of the bradyarrhythmia, and increasing peripheral vascular tone. Given that volume resuscitation alone often will not correct ongoing hypotension, attention should be quickly be focused on pharmacologic cardiovascular support once hemorrhage has been ruled-out as over-resuscitation has been shown to lead to pulmonary edema. (38, 39) Central venous monitoring should be instituted early and placement of a pulmonary artery catheter should be considered if accurate volume status cannot be assessed. Many different cardiac and vasoactive agents have been described for the initial treatment of neurogenic shock including atropine, epinephrine, dopamine, norepinepherine, and aminophylline.(40, 41) However, there is no evidence in the current literature to support that any of these therapies is definitively superior to the others. Norepinepherine is gaining ground over dopamine as the agent of choice in vasodilatory shock. Both dopamine and norepinepherine have β1 (and/ or dopaminergic) and α-adrenergic receptor stimulating effects. However, several observational studies have shown lower mortality rates with use of norepinepherine in septic shock than with dopamine.(42, 43) Whether or not these findings apply to neurogenic shock is unknown. Both dopamine and norepinepherine have inotropic, chronotropic, and vasopressive effects. Increase in mean arterial pressure with dopamine occurs primarily with an increase in cardiac output, whereas norepinepherine does so by increasing peripheral vascular resistance.(44) Therefore, dopamine infusion is probably the best initial therapy in patients with significant bradycardia. However, either norepinepherine or dopamine is an appropriate initial choice for the treatment of neurogenic shock after SCI. Epinepherine also has cardiostimulatory and vasopressive effects, however, several studies have shown evidence of significant effects on end-organ perfusion including decreased splanchnic perfusion, increased lactate levels, and decreased gastric mucosal pH.(45, 46) Phenylepherine is a pure α-receptor antagonist and while it successfully increases mean arterial pressure by peripheral vasoconstriction and increased left ventricular afterload, it can actually decrease cardiac output and cause reflex bradycardia. Atropine successfully increases both heart rate and mean arterial pressure, however, its transient effects make it more useful as a rescue drug than as an ongoing therapy. There have been a few case reports on the successful use of aminophylline, which is a non-specific adenosine receptor

antagonist, in patients with bradycardia and neurogenic shock.(41) However, more investigation into the use of this drug as a supportive agent is required before its widespread use can be recommended.

> On arrival to the ICU a dopamine infusion was started and titrated to effect. The patient's heart rate increased to 85 beats per minute and his blood pressure improved to 125/70 mmHg. A central venous catheter was placed revealing a central venous pressure (CVP) of 14. His urine output remained > 30cc/h. Over the next 36 h the dopamine was weaned until it was no longer required to sustain an adequate blood pressure and his resting heart rate remained 60–70 beats per minute.

WHEN SHOULD PACEMAKER INSERTION BE CONSIDERED?

Most patients with SCI and neurogenic bradycardia will respond to pharmacologic intervention. The need for inotropic and vasopressor therapy is usually transient, resolving within 24–48 h. Mean arterial pressure and heart rate in most patients return to baseline values within 5–7 days of high thoracic or cervical cord injury.(30) Following the acute phase of sympathetic atony, a state of autonomic hyperactivity, known as autonomic hyperreflexia, ensues over a course of weeks to months. This subsequently persists as a chronic state.(30)

There are numerous case reports in the literature of patients with bradycardia and hemodynamic instability refractory to standard medical therapy. Temporary transthoracic, transvenous as well as permanent pacemaker placement have been successfully reported in these patients.(35, 37, 47–49) Emergent transthoracic or transvenous pacing is obviously indicated in the patient with symptomatic bradycardia, hemodynamic instability, or ventricular standstill refractory to chronotropic therapy. Transthoracic pacing is the least reliable of these methods and should only be used as a temporizing method prior to transvenous pacing or temporary pacemaker placement.(34) While most bradyarrhythmias associated with SCI will resolve within 1 week, some persist for up to 6 weeks.(35, 36) A few with cervical cord injuries may persist indefinitely. Currently, there is no definitive data clarifying the need or optimal time frame for permanent pacemaker placement in patients with refractory bradycardia after SCI. Patients most likely to require permanent pacing are those with complete injuries at C5 or higher.(35, 40) Given our current knowledge, consideration for permanent pacemaker placement should be considered in patients with SCI at or above C5 with recurrent events of symptomatic bradyarrhythmias persistent after 2 weeks of injury.

> After successfully weaned off of dopamine on day 3, the patient was transferred to the ward in preparation for rehab facility placement. He had one episode of symptomatic bradycardia requiring atropine within the first week. After this he had no further episodes of bradycardia requiring intervention. Pacemaker placement was not required. The patient was transferred to an appropriate facility to begin his rehabilitation.

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32 Oliguria
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A 60-year-old male with coronary artery disease, diabetes mellitus, and a baseline creatinine of 2.5 mg/dL is scheduled for an endovascular abdominal aortic aneurysm repair. The surgeon expects to perform a contrast angiogram in the operating room and prescribes 1,200 mg N-acetylcysteine (NAC) to be taken orally twice daily for the 2 days prior to and following the procedure. In anticipation of a significant dye load (> 1.5 mL/kg), the patient also receives 300 mL of an intravenous infusion of 150 meq/L sodium bicarbonate in the hour prior to the procedure. In the course of graft deployment, the iliac artery is ruptured and requires open repair, significantly lengthening the operation and resulting in 3 L blood loss associated with a transient period of intraoperative hypotension, and subsequent administration of 8 units of packed red blood cells and 6 units of fresh frozen plasma. Post-operatively, the patient is kept intubated and admitted to the surgical intensive care unit for observation. The sodium bicarbonate infusion is continued at 100 mL/h for another 8 h and approximately 30 cc/kg/h of urine is measured overnight. However, by the next morning, his creatinine is 4.0 and urine output is minimal despite normal systolic blood pressures. The foley catheter is flushed with 60 cc of sterile saline, of which 50 cc returns into the collection bag. A renal ultrasound confirms no evidence of hydronephrosis. Fractional excretion of sodium is calculated >1%. Central venous pressure is 12, and the arterial line tracing reveals no respiratory variation. A fluid bolus of 500 cc is given and no increase in urine output is detected over the following 2 h. Administration of 60 mg IV furosemide results in a modest increase in urine output to 40 cc/h for 1 h, dropping off to <10 cc/h thereafter. By evening of post-operative day (POD) 1, a chest radiograph is obtained and reveals pulmonary edema. By POD 2, the central venous pressure is 15 and repeat blood work reveals blood urea nitrogen (BUN) 80, creatinine 4.5 and potassium 5.8. A dialysis catheter is placed in the right internal jugular vein and continuous renal replacement therapy (CRRT) is initiated. During the first 24 h, CRRT facilitates normalization of BUN, creatinine, and electrolytes and yields a net fluid loss of 2.5 L. The patient begins to make 30 cc/h of urine and CRRT is discontinued after 48 h. The oxygen requirement is reduced, chest X-ray clears, and the patient is extubated uneventfully. In approximately 10 days, the patient is back to his baseline renal function and is discharged to a skilled nursing facility.

OLIGURIA: GENERAL OVERVIEW
What Is Oliguria?
Oliguria is defined as acute onset of decreased urine output less than 0.5 ml/kg/h or 400 ml/24 h in an adult. The context of the development of oliguria in the surgical patient is as important as the recognition of the event, as there is a broad spectrum of possible hemodynamic, mechanical, and toxin-related etiologies and early, appropriate intervention may mitigate progression from low urine output to acute renal failure (ARF). It should be acknowledged that the development of oliguria does not necessarily signal the beginning of irreversible renal failure; conversely, compromised renal function as measured by the kidneys ability to clear solute can be present in the setting of brisk urine output. Accordingly, the other major component of assessing potentially compromised renal function involves examining the metabolic clearance of the kidney by measuring nitrogen metabolism waste products, namely, urea and creatinine.

How Do We Define ARF? What Are the RIFLE Criteria?
While the term "ARF" has been employed for many years, there has been no agreement as to the diagnostic criteria, and consequently, the determination of the significance of changes in renal function is not standardized.(1) To enable better understanding of the etiology, outcomes, and potential treatment for renal injury, the "RIFLE criteria" were developed from consensus conference and adopted to classify renal dysfunction in three categories (*R*isk, *I*njury and *F*ailure) with two levels of outcome (persistent ARF or "*L*oss," and *E*nd-staged kidney disease) (Table 32.1).(2) Additionally, the term "acute kidney injury" (AKI) has been suggested to replace the nebulous "ARF" and better describe the three-tiered spectrum of renal dysfunction delineated by the RIFLE system. Few investigators have applied the RIFLE criteria to assess AKI in post-surgical patients.(3, 4) Additionally, while there is a move to adopt these criteria, contradictory definitions persist and there is no consensus, even with the consideration of the RIFLE system, as to when to initiate renal replacement therapy (RRT), either in the form of continuous or in the form of intermittent hemodialysis.(5, 6)

What Is the Incidence and Outcome of ARF in Critically Ill Patients?
While the definitions of ARF and indications for hemodialysis may be debated, there is little question that the development of renal failure is a harbinger of poor outcome in the intensive care unit. By RIFLE criteria, the incidence of ARF in critically ill patients is characterized between 15 and 80%.(7) Dialysis-dependent renal failure only occurs in 3.4 and 4.9% of critically ill patients, but confers an estimated 60 and 70% mortality and up to 30% of survivors may require chronic dialysis within 3 years.(5) The mortality of

Table 32.1 RIFLE Classification Scheme for ARF (2).

	GFR Criteria	Urine Output Criteria
Risk	Serum creatinine (Cr) increased 1.5× *Or* decrease in GFR > 25%	<0.5 mL/kg/h for 6 h
Injury	Cr increased 2× *or* decrease in GFR > 50%	<0.5 mL/kg/h for 12 h
Failure	Cr increased 3× *or* decrease in GFR > 75% *or* Cr decreased by > 4 mg/dL	<0.3 mL/kg/h for 12 h *or* anuria for 24 h
Loss	Persistent ARF, complete loss of kidney function for > 4 week	
End-stage renal disease	End-stage renal disease for > 3 month	

GFR, glomerular filtration rate. The classification system includes separate criteria based on creatinine and urine output and assessment is based on the worst possible value, if both are present.

ARF is increased with each additional organ system dysfunction, particularly in the setting of sepsis. Advanced age predicts worse outcomes after renal failure because of reduced ability to recover renal function. It is therefore imperative to identify risk factors for the development of ARF, apply supportive measures to prevent development, and correct causative elements as soon as they are recognized to minimize the long-term impact on renal function.

What Are the Potential Causes of ARF?

Acute renal dysfunction occurs in the setting of a broad spectrum of disease and injury. To simplify the approach to diagnosis and treatment, ARF may be examined according to three broad anatomic/physiologic categories: pre-renal, renal, and post-renal. In reality, acute renal dysfunction is often multifactorial, transcending this classification. For the purpose of systematic evaluation of acute onset oliguria, such groupings may be useful, in that the pre-renal and post-renal disorders present potentially reversible risk to kidney function with directed interventions to facilitate adequate perfusion to the kidney and drainage of the urinary system. The disorders that affect the renal parenchyma itself are largely treated with supportive care until renal recovery or nephron loss is established.

The often-employed term "pre-renal azotemia" refers specifically to the reduction in renal function secondary to a state of hypoperfusion of intact renal parenchyma. The reduction in renal blood flow may be due to systemic hypoperfusion of various etiologies, including blood loss, myocardial dysfunction, or redistribution of intravascular volume following surgery or infection. Isolated renal artery flow changes due to vasoconstrictive drugs or intravascular interventions may also contribute to ARF, even in the absence of hypotension, particularly if there is atherosclerotic disease or chronic renal insufficiency present at baseline. Abdominal compartment syndrome should also be considered in this category, as the increase in intra-abdominal pressure >30 cm H_2O with aggressive volume resuscitation affects renal blood flow.(8)

Renal parenchymal etiologies of acute renal injury include glomerulonephritis, vasculitis, acute interstitial nephritis, and tubular processes. The renal tubules are the region of the highest metabolic demand and as a result, the area of the kidney most at risk for damage from lack of oxygen. The hypoperfusion of pre-renal azotemia, therefore, may lead to frank ischemia, cellular ATP depletion, and allow acute tubular necrosis (ATN) to develop via oxidative injury. Alternatively, drugs such as aminoglycosides, intravenous contrast media, and even myoglobin or hemoglobin may cause direct toxicity to the tubules.

Post-obstructive uropathy develops when urinary flow is impeded at any level along the urinary tract. In the intensive care unit, urinary catheters and stents are commonplace, and manipulation or malpositioning of these devices can result in unintended obstruction. Trauma, coagulopathy, and post-surgical conditions may result in gross hematuria requiring clot irrigation to achieve adequate drainage. More proximal obstruction may occur due to pre-existing nephrolithiasis, pelvic hematoma, or iatrogenic injury to the upper urinary system.

Who Is At Risk for ARF?

The best estimates of the incidence of ARF in hospitalized patients attribute approximately 70% of new cases to pre-renal and/or nephrotoxic etiologies (9, 10) with 50% as a cause of sepsis or septic shock.(11) Those patients at highest risk for developing ARF have comorbid conditions that contribute to pre-existing chronic renal impairment, including hypertension, diabetes mellitus, and congestive heart failure. Aging is characterized by a decline in renal function, placing the elderly at particular risk for renal injury.(12) Furthermore, renal dysfunction in this population may be underappreciated due to normal range creatinine with reduced muscle mass and poor nutrition, even in the face of reduced GFR.

Surgical interventions pose unique challenges to renal function. Through preoperative fasting, intraoperative fluid and blood losses, and use of vasoactive anesthesics, patients are subjected to extremes of intravascular volume depletion and hemodynamic changes which may result in up to 30–45% reduction in GFR, urine volume, and sodium excretion. Patients with normal baseline renal function generally tolerate these acute stressors with no measurable evidence of renal injury, but pre-existing renal insufficiency, exposure to nephrotoxins, post-operative sepsis, or repeated episodes of hypotension substantially increase the liklihood of ATN or permanent nephron loss. One of the highest risk procedures is open abdominal aortic aneurysm repair, particularly if supra-aortic clamping resulting in total renal ischemia is required.(13) With the development of endovascular techniques, the risk of prolonged anesthesia, fluid losses, hemodynamic instability, and hemorrhage have been lessened to a substantial degree. A recent population analysis comparing outcomes of open versus endovascular elective abdominal aortic aneurysm repair (EVAR) revealed lower rates of ARF (5.5% vs. 10.9%, $P < 0.001$) and need for dialysis (0.4% vs. 0.5%, $P = 0.047$) in the endovascular group (14).

Endovascular techniques do not prevent renal injury, however. Showering of atheroemboli due to intravascular trauma from catherization and stent deployment has been associated with distal limb and intestinal ischemia, livedo reticularis, and renal failure.(15–18) Additionally, renal perfusion defects with consequent renal injury

have been reported after EVAR.(19) Supra-renal fixation of aortic stents is sometimes necessary and has been associated with both transient and permanent renal injury.(20, 21) Perhaps the most significant risk to renal function after EVAR is the use of intravenous contrast media to plan and execute the procedure. Indeed, although EVAR is associated with fewer short-term complications than open aneurysm repair (22, 23); some authors have found elevated serum creatinine >1.8 mg/dL to be a predictor of poor outcome.(24, 25) While vascular patients tend to have multiple risk factors for development of post-procedural ARF, even pre-existing renal insufficiency is not necessarily thought to be a contraindication to EVAR (26, 27), particularly if measures to prevent contrast-induced nephropathy are undertaken.(28)

What Is Contrast-Induced Nephropathy?

Contrast-induced nephropathy (CIN), defined as increase in serum creatinine greater than 25% or 0.5 mg/dL within 3 days of intravascular contrast administration in the absence of alternative cause, is third most common cause of new ARF in hospitalized patients. (29) Developing in 0–10% of patients with baseline normal renal function, CIN usually develops without oliguria, with creatinine levels peaking within 3–5 days, and baseline return of renal function within 7–10 days. However, the mortality after CIN may be as high as 35% and development of renal failure after contrast administration is an independent predictor of mortality.(30)

Intravenous contrast, particularly higher osmolar preparations previously employed, is thought cause ischemia-reperfusion injury as well as direct cytotoxicity to the renal tubules.(31) The hyperosmolar, hypertonic nature of the solution yields diuresis, and natures, leading to tubuloglomerular feeback and a reduction in GFR, which is reinforced by increased endothelins. Additionally, there is direct cytotoxicity to the tubules by way of reduction in transepithelial resistance and membrane permeabilization, increased cytoplasmis vacuolization and apoptosis via nitric oxide.(32)

Who Is At Risk for CIN?

In patients with comorbid disease or concurrent administration of other nephrotoxic drugs, the incidence of CIN can be as high as 25% and the development of additional permanent renal dysfunction is possible.(33) Pre-existing renal impairment is a notable risk factor for CIN, developing in up to 20% in patients with creatinine> 2.5.(34) Although female sex itself does not confer increased risk for CIN, like the elderly, who may have normal creatinine, but reduced creatinine clearance, women have relatively reduced GFR, which may predispose to CIN.(35) Those with pre-existing renal dysfunction and diabetes mellitus have been shown to be at highest risk of all.(31) Just as intravascular volume depletion may lead to pre-renal azotemia, dehydration has been shown to contribute to CIN as well.(36)

How Can I Prevent CIN in My Patients?

A reasonable approach to prevention of CIN includes identifying patients at risk, minimizing (or eliminating) exposure to intravascular contrast, avoiding other nephrotoxins, and reducing the risk of pre-renal azotemia through adequate intravenous hydration. Given the increasing reliance on contrast-based imaging, it should come as no surprise that there have been many studies of various methods and pharmacologic agents to prevent CIN. Despite this, few interventions have demonstrated consistent, reproducible results in clinical trials. Table 32.2 provides a summary of the major investigations with evidenced-based recommendations where possible.

Decreasing contrast exposure can be achieved through use alternative agents, dosing or imaging modalities. Historically, ionidated contrast was employed which conveyed a significantly higher osmolar load and resultant injury to the kidneys; CIN has been significantly decreased through employing low-osmolar agents and limiting dosing.(31, 37, 38) While computed tomography (CT) is often used to plan EVAR, increasing the interval between pre-operative contrast studies and stent deployment can allow time for renal functional recovery. Alternatively, some authors have reported the use of non-contrast CT and intravascular ultrasound preoperatively (39, 40), or even CO_2 angiography during EVAR, although this practice may increase fluoroscopy and operative times.(41) Magnetic resonance angiography was once thought to be reno-protective, but with the recognition of nephrogenic systemic fibrosis, a systemic disorder caused by gadolinium contrast exposure, MRA is no longer advisable in patients with chronic renal dysfunction.(42–44)

Measures should be taken to avoid other nephrotoxic agents (e.g., aminoglycosides, non-steroidal anti-inflammatory agents) (33) and to maximize the blood flow to the kidneys in the pre-contrast and perioperative period. In fact, fluid hydration is the only active intervention that has consistently been demonstrated to reliably prevent CIN (45–47). Sodium bicarbonate infusion has also been employed in this manner and may have additional benefit through alkinalization of the urine, potentially preventing tubular damage.(48–50) Forced diuresis, including use of mannitol which is hypothesized to exert a free-radical scavenging effect, has never been demonstrated to be protective outside of rhabdomyolysis-induced renal failure, and may be injurious, precipitating dehydration and pre-renal failure.(51)

In addition to mannitol, other antioxidant therapies have been entertained for prophylactic treatment of CIN, the most notable being NAC. While NAC has been recommended on the basis of several randomized controlled trials (52–54), recent meta-analyses have come to contrary conclusions (55–57) and currently, its use is no longer advocated.(32, 58) Results have been similarly inconsistent in the vascular patient population (59–61), and its use could be associated with increased blood loss.(62) Ascorbic acid may be beneficial, but further data are required before any recommendations can be made for its use in preventing CIN.(63)

Pharmaceuticals directed at renovascular dilation have also been evaluated. Low-dose dopamine has long been thought to exert a renoprotective effect by increasing renal blood flow, but because it dilates both the efferent and the afferent artiorles, the net effect on GFR is minimal. Additionally, because it acts to inhibit sodium resorption, dopamine can also effect naturesis and diuresis, but it has neither been shown to prevent ARF nor death, (64) and its prophylactic use in coronary angiography was not beneficial in specifically preventing CIN.(65) Fenoldapam, a selective D_1 receptor agonist, reduces systemic vascular resistance while increasing renal blood flow through reversal of vasoconstrictive effects of angiotensin II and endothelin. A pilot study of fenoldapam in diabetic patients undergoing coronary angiography demonstrated reduction in incidence of CIN (66), but in another larger trial in

Table 32.2 Evidence-Based Recommendations for Prevention of CIN.

Therapy	Level of Evidence
Employ alternative imaging strategies	
Avoid high-osmolality contrast(31, 38)	1A
Decrease total contrast dose(37)	
Increase interval between contrast loads	
Employ alternate imaging modality	
MRI (no gadolinium)	
Duplex	
CO_2 angiography	
Discontinue concomitant therapies	
Nephrotoxins(33)	
NSAIDs	
Aminoglycosides	
Amphoteracin B	
Vancomycin	
Diuretics(51)	
ACE inhibitors/ARBs	
Correct volume status	
Isotonic saline(51)	1B
Sodium bicarbonate(48–50)	2B
Prophylactic agents/practices with uncertain benefit	
NAC (55, 57)	
Oral hydration(45)	
Fenoldapam(67)	
Theophylline(81)	
Ascorbic acid(63)	
Statins(82)	
Atrial naturetic peptide(73)	
Pre-procedural dialysis in chronic renal insufficiency (79)	
No evidence of benefit	
Dialysis of contrast material without pre-existing renal disease	1B
Dopamine(65)	1B

ACE, angiotensive converting enzyme. ARB, angiotensin II receptor blockers. Adapted from Meschi et al.(32)

comparison to saline hydration alone, no additional benefit was seen.(67) Similar trials with calcium channel blockers (68, 69), the non-selective adenosine receptor antagonist theophyllline (70–72), atrionaturetic peptide (73), and prostacyclin E1 (74) have failed to show significant clinical benefit in this setting either.

It is not clear that RRT can prevent the development of CIN, even though it has been demonstrated that osmotic contrast media may be cleared by the semi-permeable membranes employed in dialysis. Neither simultaneous RRT during coronary angiography (75) nor post-contrast RRT has been shown to change the outcome in CIN.

(76, 77) Pre-contrast hemofiltration has been shown in patients with advanced chronic renal failure to prevent complications (78, 79), but others have found prophylactic hemodialysis before contrast administration to be harmful (80), potentially because the acute removal of the osmotic load actually confers a relatively hypoosmotic state and may cause further movement of intravascular volume to the interstitium, effectively producing a pre-renal state.

So, I have done everything possible to prevent ARF. Now what do I do when my patient becomes oliguric?

The systematic evaluation of the patient with oliguria involves a thorough review of the pre-existing risk factors and immediate clinical history to carefully consider precipitating causes and eliminate ongoing risk to renal function. Review the patient's past medical history and make particular note of baseline renal function, history of diabetes mellitus, hypertension, and congestive heart failure. Examine recent clinical events to determine if intravascular volume or hemodynamic changes could have contributed to decreased renal blood flow. Consult the medication history to determine if nephrotoxic pharmaceuticals have been administered and discontinue them if possible. Determine if preceding interventions or operations may have caused thromboembolism to the renal arteries or obstruction of or damage to the post-renal system.

As the history is reviewed, several simple interventions may be undertaken to identify and correct the reversible causes of early renal dysfunction. Prompt recognition of the first signs of hypovolemia and/or shock and immediate resuscitative strategies based on the clinical circumstances are the first step. Unless the etiology of oliguria is thought to be secondary to congestive heart failure, administer a fluid challenge with isotonic saline or blood if acute anemia of blood loss is present. Adequate volume repletion prior to the administration of vasopressors is necessary to avoid local renovascular vasoconstriction, preserve adequate glomerulofiltration rates, and avoid the progression of renal failure. Should the oliguria continue despite fluid administration, pursue additional invasive monitoring of blood pressure, central venous pressure, cardiac output, and mixed venous oxygen saturation to guide continued resuscitation. At the same time, rule out post-renal obstruction by inserting a urinary catheter, or if already indwelling, by flushing the catheter with 30 cc sterile saline to ensure patency. Bilateral renal ultrasound can reveal hydronephrosis, but will not rule out unilateral ureteric injury. Review the operative note and confirm that there was no difficulty identifying the ureter and that it was protected throughout the dissection. If suspicion is high for iatrogenic injury, a delayed contrast study may be necessary to identify extravasation of urine into the peritoneal cavity, particularly early in the post-operative course when intra-abdominal fluid is expected due to fluid shifts.

How Can I Distinguish Between Pre-renal and Renal Parenchymal Failure?

Several blood and urinary indices may be employed to corroborate physical findings of pre-renal azotemia. Of these, the most commonly used is the fractional excretion of sodium (FENa), which measures the ratios of the sodium excreted to the sodium filtered in the following formula:

$$FENa = (\text{urine sodium/serum sodium})/(\text{urine creatinine/serum creatinine}) \times 100$$

Pre-renal azotemia is consistent with a FENa value < 1%, as in the dehydrated or low-flow state, the kidney preferentially reabsorbs almost 100% of the filtered sodium to maintain intravascular volume. In ATN, simultaneous inappropriate salt wasting occurs due to tubule damage and volume expansion happens as a result of fewer functioning nephrons. However, the FENa may be spuriously low in certain circumstances, including early postischemic ATN, CIN, myoglobinuria, glomerulonephritis, or sepsis.(83–85) Following diuretic administration, the FENa can be substantially higher even in the setting of pre-renal azotemia. In this circumstance, calculating the fractional excretion of urea is advisable.(86) Other laboratory findings that may distinguish pre-renal failure from ATN include a blood urea nitrogen to creatinine ratio greater than 20, urine osmolality greater than 350 mOsm/L, and a low urine sodium (< 20 meq/L). Furthermore, urine output improvement after the initial fluid challenge or subsequent optimization of hemodynamics signals successful restoration of renal blood flow and without development of clinically significant ATN.

Is Non-oliguric Renal Failure Better Than Oliguria? Should I Give Lasix If My Patient Does Not Respond to a Fluid Bolus?

The use of diuretics in established renal failure is a practice associated with much controversy. Historically, it had been postulated that conversion of oliguric to non-oliguric renal failure was beneficial in improving overall volume balance and facilitating earlier recovery of renal function.(87) While subsequent retrospective data suggested that diuretics may worsen renal failure and increase mortality (88), several randomized controlled trials have concluded that in established ATN, use of high-dose furosemide can maintain urine output and facilitate earlier diuresis, but has no impact on survival.(89, 90) It is now generally agreed that a response to diuretics in ARF occurs due to the preserved function of the remaining normal nephrons, and not because of a rescue or recruitment of damaged nephrons, and response to diuretic therapy may in effect diagnose a less severe form of AKI. Short-course diuretics may assist in management of fluid overload, but their use should not delay initiation of nephrology consultation which has been shown to be an independent predictor of increased mortality.(91, 92)

In this case, the etiology of AKI was multifactorial. The patient had multiple risk factors for the development of CIN, including chronic renal failure and diabetes, as well as a large volume contrast load. The instrumentation of an atherosclerotic aorta may have caused thromboembolism, and intraoperative hypotension secondary to blood loss caused renal ischemia, both contributing to the development of AKI. When oliguria developed, possible post-obstructive uropathy was excluded via renal ultrasound. Volume resuscitation was confirmed by measurement of central venous pressure. Following non-response to a fluid challenge and a measured FENa consistent with ATN, administration of high-dose furosemide did not achieve adequate diuresis in the setting of volume overload and AKI progressed.

When Should I Start Dialysis? Should I Employ Continuous or Intermittent Therapy?

The indications for RRT have long been described with the "A, E, I, O, U" mnemonic: **A**cidosis, **E**lectrolyte imbalance (particularly hyperkalemia), **I**ntoxications, volume **O**verload, and **U**remia. In the setting of AKI, the major goals of RRT include control of extracellular volume by removal of excess fluid and control of azotemia by removal of solute. Fluid and solute removal may be achieved through either diffusion through a semi-permeable membrane into dialysate solution (hemodialysis) or via convection by means of differential hydrostatic pressure across a semi-permeable membrane (hemofiltration). Hemodialysis is highly effective at the removal of small molecules along a prescribed concentration gradient. Because the flow rate required is high clearance achieved quickly allowing for interval therapy known as intermittent hemodialysis (IHD). A consequence of high flow and rapid solute clearance rates is hypotension, which is often not well tolerated by critically ill patients and may in fact contribute to worsening renal failure through sustained periods of renal ischemia. Conversely, in hemofiltration, the rate of solute removal is entirely dependent on the rate of plasma filtration, and the therapy must be delivered over significantly longer periods of time as continuous therapy such as continuous veno-venous hemofiltration (CVVH). While there have been no studies to support a reduction in mortality with CVVH versus IHD, patients receiving CVVH have been shown demonstrate less hemodynamic fluctuation and still achieve greater net volume removal.(93, 94)

Mortality rates for dialysis-dependent AKI exceed 50%, and it has been hypothesized that RRT could be initiated early to arrest the cascade of organ failure and impact survival. Unfortunately, as there is no universal consensus on what constitutes ARF, there are currently no standard criteria for the "early" versus "late" initiation of RRT and the optimal timing remains unclear.(6, 95) There are several observation studies that suggest improved survival when CVVH was instituted early in the development of AKI on the basis of moderately elevated BUN (95, 96) and early oliguria (97, 98), but the only randomized controlled trial on the subject failed to demonstrate a survival benefit.(99) High-**dose diuretic therapy in AKI has not been compared to early RRT, and the optimal dosing of RRT awaits the results of several ongoing clinical trials.(100)

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33 Hyponatremia in the surgical intensive care unit
Christine C Wyrick

A 47-year-old male is brought to the emergency room (ER) by a friend 2 days after falling down one flight of stairs while intoxicated. While he did not lose consciousness from the fall, his friend reports that he has become progressively disoriented and vomited twice this morning. His friend is unaware of any significant past medical history.

On exam, the patient is confused and somnolent, but follows commands and has a nonfocal neurologic exam. Heart rate is 72 bpm, blood pressure 116/69, respiratory rate 16, O_2 sats 97% on room air. Moderate abdominal distension is noted and the liver edge is palpated 4 cm below the costal margin. Spider angiomas are noted across the chest. Lower extremities have 1+ edema. Chest X-ray (CXR) shows hyperinflated lungs consistent with chronic obstructive pulmonary disease (COPD). Head computed tomography (CT) shows mild global atrophy and a small right subdural hematoma. Laboratory tests show sodium 124, chloride 86, creatinine 0.9, gamma-glutamyl transpeptidase (GGT) 155, aspartate aminotransferase (AST) 59, alanine aminotransferase (ALT) 62, and total bilirubin 1.2.

The patient is admitted to the surgical intensive care unit (SICU) for overnight observation. He is put on intravenous (IV) normal saline at a maintenance rate, and thiamine and folate are administered. The next morning, his oxygen saturations drop to 92% on face mask and he responds only to painful stimuli. A repeat head CT shows cerebral edema. Serum sodium is 117. He is started on 3% NaCl at 70 cc/h. Hourly serum sodium levels are drawn, and after 12 h his serum sodium is 126. His mental status and head CT improve and the 3% infusion is discontinued. Suspecting the syndrome of inappropriate antidiuretic hormone secretion (SIADH), he is placed on fluid restriction, and is also started on diazepam for delerium tremens prophylaxis. Twelve hours later, serum sodium is 125. Demeclocycline is administered, and after another 24 h the patient's serum sodium is 131. He is transferred to the floor and discharged from the hospital 3 days later with a prescribed benzodiazepine taper and referral to a local Alcoholics Anonymous chapter.

WHAT IS HYPONATREMIA?
Hyponatremia is one of the most common electrolyte disorders observed in critically ill patients, with a reported incidence ranging 14–30% in the ICU.[1] Often defined as a serum sodium level ≤ 135 mEq/l, it is associated with a poor prognosis in many disease states, [2, 3] and severe hyponatremia (Na ≤ 125 mEq/l) has been shown to be an independent predictor of in-hospital mortality.[4] Hyponatremia reflects a relative excess of total body water relative to total body sodium content, either from sodium loss or body fluid expansion.[2] In most cases, it is associated with extracellular

Table 33.1 Etiologies of Hypotonic Hyponatremia.

Hypovolemic (depletional)	Euvolemic (dilutional)	Hypervolemic (dilutional)
Diuretic therapy	SIADH	Iatrogenic
CSW	–Tumors	CHF
Mineralocorticoid deficiency	–CNS disorders	Liver cirrhosis
–autoimmune	–mass lesions	Nephrotic syndrome
–adrenal hemorrhage	–infection/inflammation	Renal failure
–infection	–degenerative	–acute
–congenital	–head trauma	–chronic
Salt-wasting nephropathy	–SAH	Primary polydipsia
Gastrointestinal losses	–Drug induced	Freshwater drowning
–vomiting, diarrhea	–Pulmonary diseases	
Third space losses	–AIDS	
–bowel obstruction	–Idiopathic	
–pancreatitis	Glucocorticoid deficiency	
–muscle trauma	Hypothyroidism	
–burns		
Sweat losses		

Source: Adapted from Verbalis et al.[2]

hypoosmolality, as sodium is the main determinant of extracellular tonicity under normal conditions. The presence of other osmotically active molecules, as seen in hyperglycemia or after infusion of mannitol-containing solutions, can cause a dilutional hyponatremia without a decrease in extracellular tonicity.[2] Hypotonic hyponatremia is further classified according to the patient's extracellular volume status (Table 33.1). Loss of body sodium through body fluids results in volume depletion, while euvolemic or hypervolemic states are seen with free water excess.[2]

WHAT ARE THE SYMPTOMS AND SIGNS OF HYPONATREMIA? HOW IS IT DANGEROUS?
Decreased extracellular fluid osmolality results in a water shift from the extracellular to the intracellular space, causing edema. This has a marked effect on the brain, since its expansion is limited by the cranium.[5] Within hours, osmotically active solutes move out of brain cells, reducing cellular volume and intracranial pressure. Because of this adaptation, chronic mild hyponatremia is usually asymptomatic.[2] When serum sodium levels fall below 125 mEq/l, symptoms such as headache, lethargy, disorientation, restlessness, nausea/vomiting, muscle cramps, and depressed reflexes begin to develop.[5] Rapid (<24 h) development of hyponatremia may result in severe cerebral edema, causing seizures, coma, brainstem herniation, and death.[5] Prompt recognition of low sodium levels and appropriate intervention are essential in preventing further neurologic injury in these patients.

WHAT IS CEREBRAL SALT WASTING?
HOW IS IT TREATED?

In the SICU, neurosurgical disorders such as traumatic brain injury (TBI) and subarachnoid hemorrhage (SAH), as well as the postoperative state, are frequently associated with the development of hyponatremia.(5, 6, 7) Cerebral salt wasting (CSW) is a disorder where an initial loss of sodium and chloride through the kidneys results in a hypovolemic state and subsequent water retention through the baroreceptor-mediated release of antidiuretic hormone (ADH), also known as vasopressin.(2, 5) The underlying cause(s) of initial salt wasting in these patients is not entirely understood. Brain natriuretic peptide (BNP) is often elevated in the serum of patients following TBI, SAH, or tumor resection in the setting of normal cardiac function.(5, 8, 9) Elevated levels of atrial natriuretic peptide have also been found in patients with CSW, though less consistently.(5, 10, 11) In addition to inducing natriuresis and vasodilatation, BNP may suppress aldosterone synthesis.(5, 8) Other factors that may contribute to the development of CSW are disruption of direct neural input or decreased sympathetic outflow to the kidneys, resulting in a reduction in glomerular filtration rate, decreased renin release, and decreased sodium recovery in the distal tubules.(5)

Initial treatment of CSW focuses on restoring a euvolemic state. Infusion of isotonic saline both replaces sodium losses and expands plasma volume, decreasing ADH secretion by the pituitary.(2) If the patient's volume status is uncertain, giving a fluid bolus may distinguish CSW from SIADH, in which sodium levels do not respond to isotonic saline.(2, 5, 12) Hyponatremia with severe neurologic symptoms is a medical emergency and should be treated initially with hypertonic saline. Although CSW is almost always an acute condition, the rate of sodium correction should still follow current guidelines of <10 mEq/l increase in 24 h to avoid osmotic demyelination, though short intervals of rapid (1–2 mEq/l/h) correction are acceptable.(2) In cases of CSW where natriuresis and hypovolemia continue despite infusion of hypertonic saline, administration of fludrocortisone for presumed low aldosterone levels has been successful in reducing urine output and sodium loss.(11, 13–15) Evidence-based recommendations for the treatment of hyponatremia secondary to CSW are summarized in Table 33.2.

HOW DOES SIADH DIFFER FROM CEREBRAL SALT WASTING? WHAT TREATMENT OPTIONS ARE AVAILABLE?

In contrast to CSW, hyponatremia secondary to SIADH is euvolemic, resulting from free water retention despite low serum osmolality.(2, 5, 16) Because ADH secretion from the posterior pituitary is dysfunctional (rather than compensatory), administration of isotonic saline to these patients is ineffective in increasing serum sodium levels. Therefore, infusion of hypertonic saline is necessary to correct sodium levels in the symptomatic patient, with frequent monitoring of serum sodium levels to prevent overly rapid correction.(2, 16, 17) Loop diuretics should be given if volume overload develops, keeping in mind that solute losses (including sodium) accompany water loss.(2, 16) In asymptomatic patients, fluid restriction (not just free water) is the initial treatment of choice. However, this therapy is often ineffective unless fluids are restricted to 800–1,000 cc/day, which is often not feasible in

Table 33.2 Evidence-Based Recommendations for Treatment of Hyponatremia.

Hypovolemic	
Symptomatic	
Hypertonic (3%) saline (2)	
Isotonic saline (2, 5, 12)	
Asymptomatic	
Isotonic saline (2)	
Fludrocortisone (11, 13–15)	1C
Euvolemic—SIADH	
Symptomatic	
Hypertonic (3%) saline (2, 16, 17)	
Asymptomatic	
Fluid restriction (2, 18)	1B
Demeclocycline (2, 19–24)	1B
Urea (2)	2B
Vasopressin receptor antagonists (2, 18, 28–31)	1A
Hypervolemic	
Iatrogenic	
Discontinue hypotonic fluids	
Hypertonic saline with loop diuretics (2)	
Cirrhosis/CHF	
Fluid restriction (2, 32)	1B
Demeclocycline (2)	2C
Urea (2)	2C
Vasopressin receptor antagonists—acute therapy (2, 28, 30, 32)	1A
Vasopressin receptor antagonists—chronic therapy (2, 25, 32)	2A

Source: Recommendations based on GRADE criteria, Guyatt et al.(39)

the SICU.(2, 18) Demeclocycline is a tetracycline antibiotic that induces a nephrogenic diabetes insipidus. It is highly effective in treating hyponatremia secondary to SIADH, and is currently the pharmacologic treatment of choice, but causes azotemia and can be nephrotoxic, especially in higher doses.(2, 19, 20, 21–24) Oral urea has been used as an osmotic diuretic both in the hospital and outpatient setting for chronic SIADH, but its use is complicated by poor patient acceptance and high nitrogen burden.(2)

Vasopressin receptor antagonists, collectively known as "vaptans," are a relatively new class of medications for the treatment of euvolemic and hypervolemic hyponatremia. Blocking receptors in the kidneys results in a pure water diuresis, or "aquaresis," without the solute wasting that occurs with conventional diuretics.(2, 25–27) Four drugs are in development, and IV conivaptan has been approved by the Food and Drug Administration (FDA) for short-term (4 days) treatment of euvolemic and hypervolemic hyponatremia.(2) Several randomized, blinded studies have been performed with all four medications, showing consistent, statistically significant improvements in serum sodium levels compared to placebo.(2, 18, 28–31) Although these agents predictably raise sodium levels, it is unknown whether they act rapidly enough to be used for treatment of acute, severe hyponatremia without the concomitant use of hypertonic saline.(2) Additionally, these agents increase thirst, so allowing ad lib intake of fluids by the patient diminishes their effectiveness.(2) Therefore, they should be used in addition to fluid restriction. There is a theoretical risk of bleeding complications from inhibition of vascular endothelium-mediated

release of Factor VIII and von Willebrand factor, but this has not been observed in clinical trials thus far.(2) All vaptans are inhibitors of the cytochrome P450 3A4 system, something which must be considered in long-term outpatient treatment.(2) As with all interventions for hyponatremia, serum sodium levels should be monitored to prevent osmotic demyelination from excessively rapid correction.

UNDER WHAT CIRCUMSTANCES IS HYPERVOLEMIC HYPONATREMIA SEEN IN THE SURGICAL INTENSIVE CARE UNIT? DOES TREATMENT DIFFER SIGNIFICANTLY FROM ANTIDIURETIC HORMONE SECRETION (SIADH)?

Iatrogenic hyponatremia is common and should not be overlooked. Massive resuscitation with hypoosmotic fluids such as Ringer's lactate, which has a sodium content of 130 mEq/l, can contribute significantly to hyponatremia and cerebral edema in neurosurgical patients. In the hyponatremic patient, IV medications and infusions should be in isotonic saline or sodium acetate. If symptoms develop with iatrogenic hyponatremia, hypertonic saline may be given in conjunction with loop diuretics to raise serum sodium levels.(2)

Other causes of hypervolemic hyponatremia are chronic disease states, such as congestive heart failure (CHF), cirrhosis of the liver, and chronic renal failure (Table 33.1). In these conditions, low effective circulating blood volume or renal dysfunction leads to excessive vasopressin secretion and water retention.(2) Hyponatremia develops slowly and may not be symptomatic in these patients. It indicates a poor prognosis, but it is uncertain whether this is because low sodium levels correlate with severe disease, or if hyponatremia itself affects the outcome.(2, 32) Strategies to increase sodium levels in hypervolemic hyponatremia are similar to those in SIADH, with fluid restriction being the initial treatment of choice.(2, 32) Demeclocycline, urea, and hypertonic saline can be used, but are limited by the risk of nephrotoxicity and/or volume overload, which would exacerbate underlying conditions. Clinical trials for the use of vasopressin receptor antagonists to treat hyponatremia associated with CHF or cirrhosis have been encouraging, demonstrating clear efficacy in the treatment of both hyponatremia and volume overload.(2, 28, 30, 32) Tolvaptan, an oral agent with once-daily dosing, has been shown to effectively treat hyponatremia and volume overload from CHF on a chronic basis.(2, 25, 32) Long-term follow-up did not show any significant difference in mortality or heart failure-related morbidity between the tolvaptan and placebo groups, but use of vaptans may reduce dependence on loop diuretics for symptom control in CHF.(2)

WHAT IS THE MECHANISM BEHIND OSMOTIC DEMYELINATION? HOW CAN IT BE PREVENTED?

Osmotic demyelination is a well-known, and rightly feared, complication of rapid correction of hyponatremia. In the human brain, the central pons is most commonly affected, leading to the the condition called central pontine myelinolysis (CPM). First described in chronic alcoholics in 1959, (33) CPM is manifested as a symmetric loss of oligodendrocytes and myelin in the central pons, resulting in varying degrees of neurologic disability.(34–36)

In chronic (>48 h) hyponatremia, cerebral edema is mitigated by the loss of organic osmolytes from brain cells.(34, 35, 37)

Reuptake of these solutes is dependent on the synthesis of transport proteins, a much slower process.(34, 37) If serum sodium is restored rapidly in a patient with chronic hyponatremia, brain cell shrinkage occurs. Injury to oligodendrocytes and demyelination results, possibly from disruption of the blood–brain barrier from vascular endothelial cell shrinkage, which allows inflammatory mediators access to neural tissue.(35)

Limiting the rate of sodium correction to <10 mEq/l in 24 h, or <18 mEq/l in 48 h, is the current recommendation for treating hyponatremia. Osmotic demyelination is rare below those values, even with chronic hyponatremia.(2) However, patients with malnutrition, severe liver disease, alcoholism, renal failure, or other chronic debilitating illnesses are at high risk for the development of osmotic demyelination, even with slower rates of sodium correction, and therapy should proceed with great caution.(2, 38) Short intervals of rapid increases in serum sodium (2–4 mEq/l over 2–4 h) are not dangerous if the total increase in serum sodium remains less than 10 mEq/l over 24 h, and may be necessary if a patient is having seizures.(2) Although the use of hypertonic saline is often perceived as a high-risk therapy for hyponatremia, there are no data to support that any method of treatment is "safer" given the same rate of correction.(2) Serum sodium levels should be monitored carefully regardless of the etiology of hyponatremia or the treatment chosen.

In the case presented at the beginning of this chapter, the patient most likely has a pre-existing chronic hyponatremia from cirrhosis of the liver. His head injury most likely resulted in a neurologically mediated acute hyponatremia, either from CSW or SIADH. Cautious therapy for hyponatremia was initially indicated due to his risk for developing osmotic demyelination, but rapid correction of serum sodium was later necessary due to a deteriorating neurologic status and the development of cerebral edema as seen on CT. After cessation of treatment with hypertonic saline, fluid restriction was initiated based on presumed SIADH. Demeclocycline was added as a successful adjunct to fluid restriction. Vasopressin receptor antagonists would be another treatment option in this patient.

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34 Glycemic control in the critically ill surgical patient

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A 50-year-old nondiabetic male is admitted to the Surgical ICU, after a Hartman's procedure for perforated diverticulitis. He is intubated and requires resuscitation; enteral feedings are begun on postoperative day 3. His blood glucose concentration is 190 mg/dL, for which an intensive insulin infusion is started. The ICU course is one of low hectic fevers, persistent hyperglycemia requiring frequent insulin dosing adjustments and an inflammatory response. Abdominal CT scan on postoperative day 5 demonstrates multiple loculated intermesenteric abscesses. He is urgently returned to the operating arena for re-exploration, source control, and peritoneal washout.

Upon return from the operating room, a random blood glucose measurement in this sedated patient is 18 mg/dL. His insulin infusion is held, 2 ampules of D50W are given and his blood glucose increases to 169 mg/dL. It is discovered that when he had been returned to the operating room, the anesthesia transport team had accidentally bolused the patient with an unknown quantity of insulin during his transport, at a time when caloric intake had been interrupted. Intensive insulin is reinitiated following a standard paper protocol per ICU policy.

HYPERGLYCEMIA AND ITS CONTROL: GENERAL OVERVIEW

Tight glycemic control in critically ill patients, particularly those with an extended ICU stay, has been shown to improve outcome in five prospective single center studies.(1–5) The initial zeal for infusing intensive insulin has been tempered more recently in the minds of some academicians by the announcement of unsuccessful prospective, randomized efforts at reducing mortality in intention to treat populations from the single center Leuven II study (4) and from the multi-center European Trials, Efficacy of Volume Substitution and Insulin Therapy in Severe Sepsis (VISEP), and GluControl.(6, 7) VISEP and GluControl, when closely scrutinized, were fatally undermined by protocol violations, experimental design flaws, and insufficient sample size by which to test the primary hypothesis. (8) Meanwhile, world opinion has already shifted; intensive insulin has become the de facto standard of care in ICUs because of overwhelming evidence that persistent and severe hyperglycemia is associated with inferior outcomes.(9) The battleground is less about whether tight glycemic control is worthwhile, and more about defining what is "tight." Should one maintain a stringently tight range of blood glucose of 80–110 mg/dL, as advocated by Van den Berghe (10) or are the same outcomes achievable together with less hypoglycemia by settling for a blood glucose threshold of around 140–150 mg/dL? (7, 11)

While some studies suggest that reducing blood glucose levels in critically ill patients improves outcomes, the precise target range, the optimal mode of insulin management, and the patients most likely to benefit remain unknown.

Hyperglycemia

Catabolic critically ill patients characteristically exhibit stress hyperglycemia as part of the metabolic response to injury.(12) Circulating insulin concentrations are increased during injury and hypermetabolism. However, there is a disproportionate release (five-fold) into the circulation of counterregulatory hormones including glucagon, epinephrine, cortisol, and growth hormone. These hormones promote gluconeogenesis, and more than offset the increased secretion of insulin. Moreover, the release of pro inflammatory cytokines during inflammation aggravates the hyperglycemic state; tumor necrosis factor, for example, promotes insulin resistance.(13) Glucose uptake by skeletal muscle is hindered in immobilized critically ill patients.(14) Finally, the critical care environment further amplifies the hyperglycemic response through the use of corticosteroids, adrenergic agents, and high dextrose nutritional support.

Hyperglycemia can cause harm by direct toxicity and via intracellular oxidative stress.(14) Glucotoxicity increases NF-kappa B, an intracellular regulator of cytokine production, causing a generalized increased inflammation and potential susceptibility to infection by nosocomial pathogens in hospitalized patients. Recent ultrastructural evidence demonstrates mitochondrial preservation in patients receiving intensive insulin and contrasts strikingly with those patients who remained hyperglycemic.(14) Insulin has an array of interesting properties, aside from intracellular dispersal of glucose.(15) Insulin attenuates apoptosis, is anti-inflammatory, and is a vasodilator, perhaps increasing tissue blood flow under ischemic conditions. Intensive insulin may work by limiting the number and effects of nosocomial infection.(1)

There is abundant evidence that hyperglycemia, both in diabetics and in nondiabetics, is harmful to hospitalized patients.(9, 11, 16–17) The most compelling study of 259,040 critically ill patients drawn from the Veterans Association Medical Center database network showed definitively that mortality increased by 2–3× in patients with severe hyperglycemia, defined as a blood glucose > 200 mg/dL.(17) Hyperglycemia was an independent predictor of death, starting with blood glucose of 111 mg/dL. Nondiabetics with hyperglycemia were at greater risk than diabetics. Although most patient case types sustained deleterious outcomes, surgical case types and patients with cardiovascular co-morbidities were particularly at risk, consistent with the early literature.

Severe hyperglycemia, such as seen in the case presentation, is associated with increased morbidity and mortality, including nosocomial infection. This is true for most critically ill patients, both diabetic and nondiabetic.

Tight Glycemic Control: Should It Be Done, in Whom, and How Vigorously?

Van den Berghe et al. in 2001 published a randomized controlled trial of critically ill surgical patients (Leuven I) demonstrating that tight glycemic control decreased hospital mortality by one-third, and significantly decreased a wide range of morbidities (Figure 34.1).(1) The Leuven study randomized 1,548 patients in a surgical ICU to receive intensive insulin therapy to maintain blood glucose levels between 80 and 110 mg/dL; insulin infusion was started when blood glucose exceeded 110 mg/dL. The control group received insulin infusions only if glucose exceeded 215 mg/dL and insulin was adjusted to keep glucose levels between 180 and 200 mg/dL. The study was originally planned to enroll 2,500 patients, however, the study was stopped at interim analysis due to an ICU survival benefit in favor of intensive insulin therapy (ICU mortality 4.6 vs. 8%, $p < 0.04$). The greatest improvements occurred in surgical patients with extended ICU stays (> 5 days); it was observed that increased survival followed from a decrease in nosocomial infections and multiple organ failure. Because few interventions in critically ill patients decrease mortality to this extent and was potentially transferable to heterogeneous case types, the results of Leuven I were eagerly embraced and rapidly incorporated into guidelines.(18–19) Tight glycemic control was recommended for all critically ill patients, especially surgical, by 16 professional societies, including the Surviving Sepsis Campaign and the American Association of Clinical Endocrinologists, leading to worldwide adoption of tight glycemic control.(18–19)

Leuven I employed a tight range of glucose control, aiming for blood glucose of 80–110 mg/dL; the nursing staff was well trained in the use of a paper protocol for insulin administration and relied upon point of care glucose testing that was accurate to laboratory standards.(1) Though a historic study, Leuven I was criticized by its disproportionate number of cardiac surgery patients (63%), the early use of high caloric feedings, and the measured end point of a single 6 AM blood glucose and its mean over the course of the ICU stay. Follow up single center studies, often experimentally observational, retrospective or historically controlled supported the findings of Leuven I.
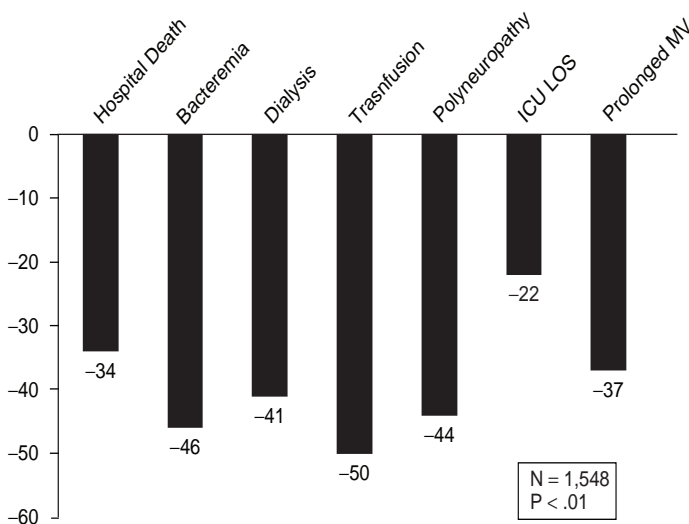
Multi-center and prospective, randomized controlled studies have not yet been able to duplicate the landmark findings of Leuven I. (6, 7, 20) A recent meta-analysis (20) examining 29 studies linking 8432 patients did not show increased survival with tight glycemic control, but did demonstrate unequivocally a higher rate of severe hypoglycemia (RR 5.13; C.I. 4.09–6.43). One explanation for this may be that benefits from tight glycemic control are offset by harm from severe hypoglycemia; alternatively, these investigations of tight glycemic control may have been burdened with inherent methodologic flaws. Most studies relied on glucose measurements using handheld glucometers that are not up to laboratory standards of accuracy. The use of paper protocols for insulin dosing is subject to nursing variability (21) and protocol violations; nursing compliance in their use is typically not reported by investigators. Frequently, these studies have been marred by heterogeneity of practice in confounding variables that influence blood glucose, such as the use of caloric feedings, choice of vasopressors, and resuscitation. There is no accepted standard for reporting glycemic control, be it a mean blood glucose or the percent of time blood glucose remains within the target range. Most importantly, many studies show overlap in mean blood glucose concentration between control and experimental cohorts, such that a significant difference in glycemic control in not achieved and the original hypothesis of tight glycemic control is not put to the test. This is not unexpected as catabolic patients, even when receiving protocol-driven intensive insulin, often manifest wide fluctuations in hourly blood glucose (11). Despite all of these pitfalls, meta-analysis did demonstrate a decrease in death (RR 0.54, C.I. 0.38–0.76) in surgical patients with sepsis.(20) Until a definitive multi-center study that is better conducted and controlled is performed without protocol violations, and because of the unambiguous harm associated with severe hyperglycemia, worldwide use of intensive insulin would appear to be the evolving standard of care, with clarity needed for appropriate case types and a desirable blood glucose target range.

The surgical literature supports tight glycemic control in trauma patients (Table 34.1). Hyperglycemia in this population of patients appears to be associated with a greater risk of infection in some studies and multiple organ failure in others. (22–28)

To date, cardiac patients,(29, 30) patients who have sustained trauma,(22–28) and generalized surgical patients would seem to benefit the most from intensive insulin.(20) It would appear the tighter the glycemic control, the greater the likely benefit, but also the greater the risk for hypoglycemia, with some (18) recommending a moderate glucose range of 80–150 mg/dL, while others insist upon a tighter range of 80–110 mg/dL.(31)

Figure 34.1 Results from Leuven I, in which 1,548 critically ill surgical patients were randomized to tight glycemic control using intensive insulin versus conventional care.

LOS, length of stay; MV, mechanical ventilation.

Table 34.1 Tight Glycemic Control in the Trauma Patient.

	Study Type	N	Patient type	End points	Conclusion	Limitations
Laird, A.	Retrospective	516	Trauma	Infection, mortality	Early hyperglycemia defined as >200 is associated with higher rates of infection and increased mortality	No standard protocol was used to control hyperglycemia
Sung, J.	Retrospective	1003	Trauma	Infection, ventilator days, length of stay, mortality	Admission hyperglycemia is associated with increased morbidity and mortality	Did not measure A1C
Bochicchio, G.	Retrospective	942	Trauma	Mortality, ventilator days, infection, length of stay	Moderate, high, worsening, and highly variable glucose levels were associated with increased length of stay, infection, and mortality	Glucose control was not standardized, latent/ undiagnosed diabetics were included
Collier, B.	Time-series with pre and post intervention group	818	Trauma	Mortality	One or more glucose levels above 150 mg/dL was associated with a mortality odds ratio of 2.16	Pre and post intervention groups did not have a significant difference in glucose levels
Toschlog, E.	Time-series with pre and post intervention group	257	Trauma	Infection, mortality, length of stay	Computerized hospital insulin protocols (CHIP) are associated with decreased morbidity but had a higher mortality	Unknown reason for increase in mortality for post-CHIP group
Sperry, J.	Retrospective, secondary analysis	850	Blunt trauma with hemorrhagic shock	Mortality, multi organ failure, nosocomial infection	Early hyperglycemia associated with improvement in survival and multiple organ failure but not nosocomial infection	Secondary analysis, unable to account for confounding variables, use of single maximum glucose level, undiagnosed/latent diabetics included
Scalea, T.	Time-series with pre and post intervention group	2129	Trauma	Infection, length of stay, ventilator days, mortality	Post intervention group with a statistically significant decrease in glucose levels were associated with lower infection, length of stay, ventilator days, and mortality	Adherence to protocol at the discretion of critical care attending, nature of study does not take into account other confounding variables

Intensive insulin driven by protocol should be used to treat severe hyperglycemia in critically ill surgical patients. The threshold range for tight, safe control should be determined by the sophistication of the individual ICU, its resources for frequent labor-intensive measurements, and its ability to standardize its practice and prevent severe hypoglycemia. In ideal circumstances, a range of 80–110 mg/dL has been recommended; blood glucose should not exceed a ceiling value of 150 mg/dL.

Hypoglycemia

VISEP, GluControl, and Leuven II were notable for the frequent observation of severe hypoglycemia, arbitrarily defined as blood glucose of <40 mg/dL.(4, 6, 7) VISEP and GluControl were stopped at interim analysis partly because of the startling incidence of severe hypoglycemia; both Leuven studies observed a higher risk of death (OR, 3.2 in surgical patients; 2.9 in medical patients) in the cohort with severe hypoglycemia.(32) The incidence of severe hypoglycemia from the cohort of patients that received intensive insulin in seven studies (1, 2, 4–7, 33) ranged from 4 to 19%. Is severe hypoglycemia merely a biochemical nuisance, one without clinical impact? Van den Berghe maintained that in no single case of hypoglycemia was any apparent clinical consequence observed after studying 2748 critically ill patients.(31)

Vriesendorp and colleagues (34, 35) published two studies examining the risk factors and outcomes of severe hypoglycemia, which they defined as a blood glucose <45 mg/dL. Risk factors identified included renal failure, interruption of caloric intake without adjustments in the insulin infusion, sepsis, and the use of vasoactive infusions. Renal failure prolongs the half-life of insulin, leading to insulin accrual and also attenuates renal neoglucogenesis. Sepsis and the use of vasoactive infusions are markers for severity of illness. The Leuven II study (4) with a severe hypoglycemic rate of 18.7% was notable for a sicker population of medical patients with a very high hospital mortality rate, 38.6%. The GluControl study (7) similarly showed that severity of illness increased the likelihood of severe hypoglycemia; ICU mortality was high in the severely hypoglycemic subgroups, whether patients were randomized to the tight glycemic control arm (80–110 mg/dLm; death 32.6%) or to the moderate glycemic control arm (140–180 mg/dL; death 53.8%).

A nested case–control study of 156 patients with severe hypoglycemia found no causal link between hypoglycemia in the ICU and death when case and control subjects were matched for risk factors.(34) However, there were two observed cases of hypoglycemic coma and one patient experienced a seizure. Krinsley and Grover (36) studied 102 patients with severe hypoglycemia and compared these against 306 matched controls, both groups originating from a community hospital mixed ICU. Severe hypoglycemia independently increased the risk of death, more than doubling its likelihood (OR 2.27 [1.4–3.68]). Mortality was extraordinarily high in both groups, 55.9% in patients with severe hypoglycemia and 39.5% in the matched controls. Increasing severity of illness—in the form of mechanical ventilation, septic shock, and APACHE II severity of illness score—once again increased the risk of severe hypoglycemia. A sensitivity analysis showed the benefits of tight glycemic control considerably outweighed the risks of severe hypoglycemia. With this study, the significance of severe hypoglycemia was juxtaposed against the greater value of tight glycemic control.(36)

The brain, which can neither produce nor store glucose, relies on blood glucose delivery for energy. Neuroglycopenia is clearly harmful.(37–39) Imaging studies of patients with sustained hypoglycemia demonstrate anatomic alterations throughout the cerebral cortex, cerebellum, and brainstem.(37) Reperfusion of glucose following treatment of hypoglycemia may induce oxygen-free radicals that can cause neuronal death.(39) Neuroglycopenia is most especially dose and time dependent. By example, hours and hours of a blood glucose concentration of 25 mg/dL is more harmful than a concentration of 10 mg/dL for a period of minutes. Profound and very prolonged severe hypoglycemia (blood glucose <20 mg/dL for >5 h) caused brain death in monkeys.(38) Moreover, overly exuberant treatment of hypoglycemia resulting in glucose overshoot and reperfusion apparently generates oxygen-free radicals that cause neuronal death.(39)

Fortunately, coma from functional brain failure is not uncommon and reversible, while coma from brain death is rare, especially in the ICU. A comparison of the characteristics of functional brain failure versus abject brain injury is outlined in Table 34.2. The high frequency of blood glucose measurements that can occur in the ICU allows interception of early hypoglycemia and prevents prolonged neuroglycopenia and brain injury. Complete recovery follows the vast preponderance of episodes of clinical hypoglycemia, even when severe. This may account for why there are so very few reports of documented individual patient injury from severe hypoglycemia despite its high incidence in the critically ill and injured.(40, 41) The frequency of blood glucose monitoring correlates inversely with the frequency and magnitude of severe hypoglycemia.(42) For many, however, practitioners will be sitting on the horns of a dilemma: avoiding severe hypoglycemia while practicing tight glycemic control.

Severe hypoglycemia is an independent predictor of death and must be avoided. Common antecedents to hypoglycemia include renal insufficiency and interruption of caloric intake without altering insulin administration. The consequences of severe hypoglycemia are dependent both on its magnitude and on its duration. Intensive insulin poses a substantial risk of severe

Table 34.2 Functional Brain Failure Versus Brain Injury.

	Functional Brain Failure	Brain Injury
stupor or coma	reversible	irreversible
Frequency	very common	Rare
Mechanism	Metabolic demands exceed energy (glucose) supply	1. Very prolonged lack of energy 2. DNA damage from reactive O2 species
Duration of hypoglycemia	Minutes	Hours
Severity of hypoglycemia	<40–50 mg/dL	<20 mg/dL

hypoglycemia; use of intensive insulin mandates rigorous adherence to a protocolized approach together with the most frequent degree of blood glucose monitoring possible given the limits of each ICU.

Insulin administration and glucose monitoring

Insulin administration is typically given in a manner regulated by paper protocol. Paper protocols provide some standardization, but are unwieldy and not able to adjust quickly enough to changing conditions when patient illness fluctuates. Most protocols require input from 1, or at most 2, blood glucose measurements and provide guidance on a corresponding insulin dose adjustment. Blood glucose measurements are typically obtained using handheld glucometers for reasons of expediency; blood samples are frequently obtained every 1–2 h in unstable patients. This combination of paper protocols, intensive insulin changes, and frequent manual blood glucose measurements has had the unintended consequence of significantly increasing the bedside nursing workload. Some estimates suggest that each maneuver requires approximately 5 minutes of every hour, or nearly 2 h of nursing time out each 24-h day; such a workload no doubt contributes to resistance in initiating intensive insulin and represents an obstacle to tight glycemic control.(21)

Software-driven insulin dosing is now emerging, with several commercially available products, including Glucocommander, EndoTool, and the Glucostabilizer. Software-directed dosing is more sophisticated in that it integrates all of the previous blood glucose values and all of the previous insulin adjustments to determine the next best insulin dose. These programs have been tested extensively in thousands of patients; they achieve tighter glycemic control, stay within the desired set glucose range for a greater length of time, and lessen severe hypoglycemia.(43, 44)

Blood glucose monitoring may be the weakest link in the chain of effectuating safe glycemic control. Handheld glucometers, for reasons of convenience and instantaneous results, have become the de facto standard of blood glucose measurement in ICUs. Early generations of these devices were aimed at Type 1 diabetics who might require a fingerstick capillary measurement once or twice daily, aiming for moderate glycemic control. This device, co-opted for use in the intensive care environment, is

Table 34.3 Recommendations and Supporting Evidence (references in parentheses).

Recommendations	Recommendation, Quality of Evidence
Severe hyperglycemia, defined as a blood glucose >200 mg/dL is deleterious, and is an independent risk factor for death in critically ill and injured patients. (1, 3, 4, 9, 17)	1A
Achieving moderate glycemic control, in a range of 80–150 mg/dL will lead to improved outcomes while minimizing harm for patients in most ICUs. (1–5, 9–11, 18)	2B
Achieving tight glycemic control, in a range of 80–110 mg/dL, will lead to improved outcomes but at a higher risk of severe hypoglycemia, and should be deployed by ICUs that are resource-intensive, and very dedicated and experienced in the process of using frequent glucose monitoring in conjunction with intensive insulin. (42)	2B
Septic surgical critically ill patients and patients after cardiac surgery are the most likely to benefit from tight glycemic control. (1, 11, 20, 29–30)	1A
Surgical critically ill and injured patients, including those who sustain trauma, will benefit from tight glycemic control. (1, 2, 22–28)	2B
Severe hypoglycemia, defined as a blood glucose <40 mg/dL, is harmful, and may raise the risk of death. (4–7, 32–36)	1A
Handheld glucometers are commonly used in the ICU setting, but are frequently and significantly less accurate than laboratory methods for measuring blood glucose; these devices frequently overestimate blood glucose when in the hypoglycemic range. (45–47)	1B
Software guided insulin dosing is preferred over the more common technique of paper-driven algorithms. (43–44)	1C

routinely applied to patients with anasarca on vasopressors and with derangements in peripheral perfusion and called upon to facilitate much tighter glycemic control. These devices were never intended for accurate measurements in these more challenging and critically ill patients and represent relatively crude and infrequent, random, and episodic monitoring.

Recent evaluations of glucometers in the ICU now prove their shortcomings; glucometers are reasonably accurate within the normal range of blood glucose, but derangements below and above the normal range are not reliably portrayed. Kanji showed that glucometers using capillary blood significantly underestimated the severity of profound hypoglycemia, the very circumstance in which accuracy is most desirable.(45) This finding was complemented by the observations of another study (46) in which glucometer readings were paired with laboratory measurements, during which it was discovered that capillary measurements overestimated the true blood glucose concentration in 83% of values. Nineteen percent of matched pairs did not meet

normal laboratory standards for reliability. Vasopressor use and peripheral edema amplified the likelihood of nonagreement or inaccuracy of blood glucose measurements.(46) Industry can be expected to fill this void, as numerous companies are presently pursuing development of a continuous or near-continuous glucometry device.(47)

Buttressing these weak components, i.e., insulin dosing strategies and glucose monitoring techniques, should assure providers of safer and tighter glycemic control. This kind of control will lead to less glycemic variability, a measuring stick for the frequent wide fluctuations seen in catabolic hosts, and which recently has been shown to be a predictor of death in critically ill patients. (48, 49) It may also very well be that these crude applications of insulin dosing and glucose measurements have hindered the pace of research in the quest to validate the original success and findings of Leuven I.

Inefficiencies accruing from paper-driven insulin protocols in combination with inaccuracies from hand-held glucometer measurements contribute to glucose variability, both a delay in achieving the target blood glucose and staying within the desired glucose range. Technologic improvements will make widespread the use of software-driven insulin dosing, titrated to a glucose range facilitated by continuous blood glucometry. The ease and frequency of blood glucose measurements will make possible tighter glycemic control and will set aside the fear of hypoglycemia expressed by the nursing staff.

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35 Postoperative anemia: Risks, benefits, and triggers for blood transfusion

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> A 22-year-old healthy male undergoes an uneventful splenectomy for splenic rupture after a motor vehicle crash during which he sustains no other injuries. His postoperative hemoglobin is 7.5 g/dL. Should he be transfused?

INTRODUCTION

Anemia and the decision of whether to transfuse are common issues addressed daily in the intensive care unit (ICU). Almost 95% of patients admitted to an ICU have a hemoglobin level below normal by ICU day 3 and 25–85% of ICU patients will receive a blood transfusion depending on their length of stay.(1–4) The etiology of anemia in critically ill patients is multi-factorial. Patients lose blood from trauma, gastrointestinal disorders, and repeated phlebotomy. In addition, they have a decreased ability to produce red blood cells (RBCs) because of sepsis, iron deficiency, and low erythropoietin concentrations related to inflammation. (5–7) Debate over an appropriate "transfusion trigger" has intensified in recent years due to concerns regarding the safety and risks of transfusions. Transfusion of blood has been linked with transmission of infectious diseases, such as hepatitis and human immunodeficiency virus (HIV), and has been independently associated with greater risk of nosocomial infection, multiple organ failure, and mortality.(1, 8–12) Although transfusion carries identifiable risks, anemia can also be associated with poor outcomes, making the decision to transfuse often complicated and multi-factorial.

COLLECTION AND STORAGE OF BLOOD

Blood collected from donors can be separated into multiple components included packed red blood cells (PRBCs), platelets, plasma, cryoprecipitate, fresh frozen plasma, and granulocytes. In 2005, over 29 million units of blood components were transfused, with nearly 49% (14.2 million units) being PRBCs alone (2005 Nationwide Blood Collection and Utilization Report, www. aabb.org). An understanding of blood preparation and storage is critical due the potential implications and risks associated with transfusion of old blood and availability of special products such as leukocyte-reduced PRBCs.

Packed red cells are prepared through differential centrifugation with an average volume of 250 cc, corresponding to a hematocrit level of 60–80%. PRBCs have a shelf life of approximately 35–42 days when stored in preservation solutions containing citrate which chelates calcium. A number of authors have studied the biochemistry of corpuscular and cytosolic changes during storage. RBCs undergo a marked depletion in 2,3-diphosphoglycerate as well as adenosine triphosphate. Furthermore, their morphology changes from biconcave discs to spheroechinocytes as a result of membrane changes, lipid peroxidation, and membrane phospholipids vesiculation.(13) The net biochemical effect may lead to adverse clinical consequences in oxygen delivery.

Some authors have argued that transfusion of older stored blood results in increased morbidity,(14) nosocomial infections,(15) and mortality,(16) although other data refutes these claims.(17, 18) Two large, prospective observational studies have demonstrated no increase in morbidity and mortality with using blood with a shelf life ranging from 16 to 21 days.(1, 12) The effect of shelf life on clinical outcomes lacks a well-designed randomized study and thus remains an ongoing topic of debate.

Leukocyte-Reduced Blood Transfusion

In an attempt to identify potential strategies for decreasing rates of transfusion-related morbidity, many investigators have studied the effects of leukocyte-reduced RBC units. Early evidence in transplantation literature suggested an immunosuppressive effect of transfusion, referred to as transfusion-related immunomodulation.(19, 20) Improved allograft survival in transplant recipients receiving pre-transplant blood transfusion as well as the documentation that leukocytes in stored blood may activate a pro-inflammatory cytokine response led to the hypothesis that leukocyte-depleted PRBCs may reduce immune response and subsequent associated morbidity.(21–23) Leukocyte reduction is achieved through centrifugation or filtration with the elimination of nearly 100% of leukocytes from an individual sample. This can be effective in reducing transmission of cell-associated viruses, especially cytomegalovirus, herpes virus, and Epstein–Barr virus, as well as reducing transfusion-related febrile reactions and acute lung injury.(24) The outcomes of studies in non-critically ill patients receiving leukoreduced blood transfusions demonstrated conflicting results, with variable rates of infection and benefit depending on the study design and patient population. Two meta-analyses of randomized trials comparing standard versus leukoreduced blood transfusion in post-operative patients have been performed. Vamvakes et al. concluded that there was no consistent benefit to leukoreduction, while Fergusson et al. suggested a slight benefit in reduced rates of infection in leukoreduced-transfused patients. (25, 26) A recent randomized control study in critically ill trauma patients showed that leukoreduction of RBCs had a small but non-significant effect on rates of infectious complications.(22) Although the study was limited by its relatively low statistical power, the authors did additionally conclude that there was no effect on the rates of febrile episodes, mortality, length of stay, or severity of organ dysfunction with the use of leukoreduced transfusion. The effects of leukocyte reduction and outcomes in patients receiving these transfusions remain an active area of research.

Indications for Transfusion

The traditional major indications for transfusion of PRBCs were to improve oxygen delivery to tissues by increasing oxygen-carrying capacity of blood and by increasing intravascular volume and, thereby, cardiac output. Oxygen delivery (DO_2) is defined by the equation

$$DO_2 = \text{Cardiac output (CO)} \times [(PaO_2 \times 0.003) + (Hgb \times 1.34 \times SaO_2)]$$

$$Hgb = \text{hemoglobin}$$

This equation suggests that hemoglobin, in addition to cardiac output, is the major determinant of DO_2. For example, increasing hemoglobin from 7 to 10 g/dL would increase DO_2 by nearly 50%. Historically, it has been suggested that transfusions, in some cases to a goal hemoglobin of 12 g/dL, serve to maximize oxygen delivery and are critical in management of the postoperative or critically ill patient.(27) In 1982, Allen and colleagues suggested that the target transfusion values for postoperative patients be set at a hemoglobin level of 10 g/dL and a hematocrit of 30%, thus creating the *10/30 rule*, which was widely adopted throughout medical practice.(28) Despite its popular acceptance, the *10/30 rule* has never been supported by a randomized clinical trial. Many other authors have attempted to address the goals of resuscitation of critically ill or postoperative patients by optimizing oxygen delivery.(29–32) Although additional hemoglobin may serve to increase the calculated value of O_2 delivery, the clinical benefit remains unclear. It has been suggested that post-operative surgical patients may have a decreased morbidity and mortality when oxygen delivery is increased through blood transfusion.(32) However, a recent review of the literature cites multiple studies which suggest that PRBCs have a limited ability to augment tissue oxygen delivery and states that transfusion should be guided by physiologic and clinical parameters rather than theoretical benefit.(33) Additionally, Dietrich et al. showed that patients transfused with approximately 3 units of PRBCs and a subsequent increase in hemoglobin from 8.3 to 10.5 g/dL had no improvement in oxygen utilization.(34) With regard to restoration of intravascular volume, there exists no well-defined randomized trial of resuscitation in hemodynamically unstable patients to determine the benefit of administration of blood versus crystalloids or colloids. This is due in large part to the ethical challenge inherent in depriving one study group of blood products during life-threatening illness. The Advanced Trauma Life Support (ATLS) Course guidelines suggest that patients with class I–II shock (0–30% of blood volume lost) may be resuscitated with crystalloid fluid alone in volumes approaching 2 L with subsequent hemodynamic re-assessment to determine response. It is generally accepted that those who fail to respond to initial fluid resuscitation or those who present in extreme hemorrhagic shock (>30% blood loss) with evidence of hemodynamic instability and/or ongoing hemorrhage should receive early blood product resuscitation.

Risks Associated with Transfusion

A wide body of recent literature has addressed the potential risks associated with blood transfusions. Historically, the focus on adverse events associated with transfusion has centered on the risk of viral disease transmission. Transmission of HIV, Hepatitis C (HCV), and Hepatitis B (HBV) to recipients of blood transfusion led to a public outcry for improved blood product safety. Subsequent research and implementation of nucleic acid testing have resulted in a drastic reduction, but not yet elimination, of viral transmission. The current estimates of risk of transfusion per unit of blood are 1:2,000,000 for HIV; 1:1,600,000 for HCV; and 1:220,000 for HBV.(35, 36) Bacterial contamination of PRBCs is extremely rare but more common in platelet transfusion. Transmission of West Nile Virus has also been reported.(37)

Despite the decreased incidence of direct viral transmission from transfusion, a number of researchers have recently addressed the increased morbidity and mortality associated with blood transfusion. Devastating immediate complications from transfusion can occur due to allergic reaction or ABO incompatibility, although the latter is a preventable problem.(38, 39) Increased mortality, length of stay, nosocomial infection, acute lung injury, systemic inflammatory response syndrome (SIRS), acute respiratory distress syndrome (ARDS), decreased immune function, and multi-system organ failure (MOF) have all been independently attributed to blood transfusion.(9, 40–42)

The CRIT study, published in 2004, showed significantly increased length of stay, rate of complications, and a significantly increased risk for death (adjusted mortality ratio of 1.65; 95% confidence interval 1.35–2.03) in patients who received transfusion when compared via propensity score to matched controls. (12) Subgroup analysis from CRIT revealed significantly increased rates of ventilator-associated pneumonia and blood stream infections (BSI).(8, 43) Additionally, the Anemia and Blood Transfusion in Critically Ill (ABC) study, conducted in Europe in 1999, was a large, prospective, observational study which documented increased morbidity and mortality in patients receiving blood transfusion. The patients in the ABC study were older, had higher Acute Physiology and Chronic Health Evaluation (APACHE) II scores on presentation, and were more likely to present in shock than those in prior studies.(1) These results were further validated by a large prospective, observational, cohort study which showed that number of transfusions was independently associated with nosocomial infections and that mortality and length of stay were significantly higher in transfused critically ill patients. (44) Multiple studies, including meta-analyses, have shown that transfusion is associated with increased rates of post-operative bacterial infections and increased rates of infection in trauma patients. (3, 11, 41, 45, 46) Rates of MOF, SIRS, ARDS have also been shown to increase in both critically ill, post-operative, and trauma patients who have received blood transfusion.(3, 10, 40, 47)

The patient was not transfused in the immediate postoperative period, as he had no evidence of hemodynamic compromise. On post-operative day 1, his hemoglobin was 6.9 g/dL and he was transfused one unit of PRBCs. A post-transfusion hemoglobin level 6 h later was 8.0 g/dL. He recovered well and was discharged to home on post-operative day 4.

Transfusion Strategies

In 1999, Hébert et al. published a landmark randomized controlled study comparing a restrictive transfusion strategy (transfusion below 7.0 g/dL, goal hemoglobin 7.0–9.0 g/dL) to a liberal transfusion strategy (transfusion below 10.0 g/dL).(3) This study, conducted by the Transfusion Requirements in Critical Care (TRICC) Investigators, was the first large, sufficiently powered randomized study to address the question of an appropriate transfusion trigger in critically ill patients. The investigators randomized 838 critically ill patients with euvolemia after initial treatment and documented anemia (hemoglobin concentration less than 9.0 g/dL within 72 h of admission) to the restrictive or liberal transfusion strategies with a primary end point of 30-day mortality. Patients with acute coronary syndromes (ACSs) were excluded. The findings of the study were striking and challenged the former paradigms of transfusion practice in critical care medicine. Although in-hospital mortality rate was significantly lower in the restrictive-strategy group (22.2% vs. 28.1%, p=0.05), the overall mortality at 30 days was not statistically significant between the two groups, demonstrating no benefit to higher transfusion thresholds. Subgroup analysis revealed a mortality benefit associated with a restrictive transfusion strategy in patients with an Acute Physiology and Chronic Health Evaluation II (APACHE II) score of 20 or less (8.7% vs. 16.1%) and in younger patients (less than 55 years of age) (5.7% vs. 13%). Patients in the restrictive arm received 54% fewer transfusions with 33% receiving no blood whatsoever (100% of liberal strategy patients received blood). Subgroup analysis of trauma patients in this trial showed similar mortality, length of ICU stay, and incidence of MOF between the restrictive and the liberal transfusion groups, suggesting no benefit of a liberal transfusion strategy.(48)

The TRICC investigators were among the first to challenge the notion that anemia below a hemoglobin level of 10.0 g/dL does not warrant transfusion. The findings of a lack of benefit of a liberal transfusion strategy and a suggestion of improved survival using a restrictive strategy in some subgroups fostered an interest in the events and mechanisms surrounding the increased mortality associated with transfusion of blood. In addition to the TRICC study, other investigators have attempted to establish a transfusion trigger, most often ranging between 7.0 and 9.0 g/dL.(49) A Cochrane Database review conducted in 2002 found 10 randomized trials addressing a restrictive transfusion strategy.(50) Although the review was dominated by the inclusion of the TRICC trial, which represented nearly 50% of the included patients and complicated by the inclusion of non-critically ill patients, the findings supported the safety of restrictive transfusion practice. Patients transfused under restrictive guidelines received 42% less blood.

Despite the enthusiasm for research on the topic and the declaration of a hemoglobin level of less than 7.0 g/dL as a potentially safe transfusion trigger by a randomized, controlled trial, there appears to be an overall resistance to change in transfusion practices among physicians. Initial prospective data from the United Kingdom suggested that although clinicians were more conservative than in prior practice with ordering transfusions, the mean pre-transfusion hemoglobin (7.8 g/dL) was still greater than that suggested as safe by TRICC. The CRIT study analyzed the clinical practice of transfusion in critically ill patients in a prospective, multiple center observational fashion. The findings suggested that little had changed in transfusion practice, with over 50% of ICU patients receiving transfusion despite a mean hemoglobin value of 8.6 g/dL.(12) This value is comparable to that described in reports from nearly a decade earlier.(4) The findings of the CRIT study also supported the notion that more liberal transfusion practice can be associated with increased morbidity and mortality.

> A 65-year-old female with a history of myocardial infarction 6 months prior undergoes an uneventful splenectomy for splenic rupture after a motor vehicle crash during which she sustains no other injuries. Her post-operative hemoglobin is 7.5 g/dL. Should she be transfused?

Transfusion in Patients with Cardiac Co-morbidities

The issue of an appropriate transfusion trigger in patients with underlying cardiac disease has generated intense debate, and much of the evidence at present is based on retrospective or observational data. Anemia is believed to be less well tolerated in individuals with co-morbid illness, such as coronary artery disease as well as with advanced age, and the historical target hemoglobin level for patients with cardiac disease has been 10.0 g/dL. Data from laboratory animals suggest that normovolemic anemia to a level of 7.0 g/dL is well tolerated in the absence of coronary disease, however, myocardial ischemia occurs earlier in animals with moderate to high-grade coronary stenosis and similar hemoglobin concentrations.(51) Cohort studies examining perioperative and critically ill patients with underlying cardiac disease have shown a disproportionate increase in mortality with increasing levels of anemia.(52, 53) Additionally, a 1958 study of Jehovah's Witness patients who refused blood transfusion documented an increased adjusted odds ratio of death in a subgroup of patients with cardiac disease when hemoglobin levels decreased to a range of 6.0–6.9 g/dL.(53) Other studies have suggested that the trend toward increased mortality occurs at a level as high as 9.5 g/dL, although this has not been proven with statistical significance.(52)

Once again, the TRICC trial provides some potential insight into the question of transfusion in the setting of underlying cardiovascular disease. Analysis of restrictive and liberal transfusion groups in the subset of patients from TRICC with underlying cardiac disease (n=357) demonstrated no significant difference in both short-term (ICU) and long-term (60 day) mortality. Those patients in the restrictive group had less multisystem organ dysfunction. In the subgroup of patients with confirmed ischemic heart disease, severe peripheral vascular disease, or severe co-morbid cardiac disease (N=257), a nonsignificant decrease in overall survival was noted. The authors concluded that restrictive transfusion strategy with a trigger of <7.0 g/dL may be safe in critically ill patients with cardiovascular disease with the exception of patients with acute myocardial infarction (AMI) and unstable angina.(3)

Transfusion in Patients with Myocardial Infarction or ACS

The question of effects of anemia in patients with AMI or ACS has been explored by two large observational studies. In elderly patients (>65 years old) with AMI, Wu et al. found that lower admission hematocrit values were associated with dramatically increased 30-day mortality.(54) The mortality rate in this study approached nearly 50% in patients with a hematocrit ≤27%. The authors recommend transfusion of PRBCs below a hematocrit of 33% in elderly patients following AMI. Although this study was one of the first to identify a deleterious effect of anemia in patients with AMI, its conclusions were limited by analyzing admission hematocrit values rather than hematocrit values associated with transfusion;(13) thus no conclusions regarding the value of transfusion can be made.

A separate study by Rao et al. attempted to answer the question of transfusion threshold in ACS via a prospective analysis focused on patient populations that were enrolled in clinical trials of aggressive interventions for management of their disease.(55) Transfusion was associated with an increased hazard for 30-day death or composite death/MI. The predicted probability of 30-day mortality in their study was higher with transfusion at nadir hematocrit values above 25% and outcomes were significantly worse with transfusion when values were >30%. The study concludes that clinicians should employ caution in electing to transfuse to an arbitrary hematocrit level in patients with ACS due to the documented increase in mortality in those patients receiving transfusion. Patients included in this analysis were younger and were more likely to undergo aggressive revascularization than those patients in the study by Wu and colleagues. These differences between studies have led other authors to suggest that there may be a benefit to higher transfusion rates in elderly patients with myocardial infarction while employing a more restrictive approach in younger patients with ACS receiving aggressive intervention.(13)

> A 45-year-old previously healthy male undergoes an uneventful splenectomy for splenic rupture after a motor vehicle crash. No further evidence of active bleeding is found intra-operatively or on post-operative imaging. During the crash, he also sustained multiple rib fractures, a left femur fracture, and a small subdural hematoma with no evidence of herniation or neurological deficit. His postoperative hemoglobin is 7.5 g/dL and he remains intubated in the ICU. Should he be transfused?

Transfusion in Multiple Injured Patients

A large percentage of the blood transfused annually in ICUs is dedicated to the acutely injured patient. This subgroup is unique in the fact that they are predominantly younger and have less co-morbidities than other ICU patients. A post hoc subset analysis of acutely injured patients admitted to 111 ICUs in 100 hospitals between August 2000 and April 2001 showed a mean age of 44.1 years, mean baseline hemoglobin of 11.1, and mean

APACHE II score of 16.9.(56) This represented 12% of the total number of ICU patients admitted during this interval, and these patients were significantly less likely to suffer from hypertension, cardiac disease, and pulmonary disease. Over 55% of the trauma patients received a blood transfusion, with an average of 5.8 units per patient. Both values were significantly increased as compared to the overall ICU population (48.2% and 4.6 units, respectively). In addition to demonstrating the frequency of transfusion among trauma patients, the authors also noted that their data showed that the current transfusion trigger in trauma patients is higher than that suggested by TRICC's restrictive strategy.

As previously noted, recommendations for the initial resuscitation of trauma patients include the use of 2 L of crystalloid followed by blood and blood products for the transient or non-responders. In addition to the American College of Surgeon's ATLS guidelines, the European multidisciplinary Task Force for Advanced Bleeding Care in Trauma supports these resuscitation practices as well as a hemoglobin "goal" of 7–9 g/dL.(57) These guidelines specifically address *pre-operative* strategies and management, with the caveat that unstable patients or those with active bleeding undergo surgical or angiographic intervention for control of hemorrhage. Post-operative management of anemia lacks such specific guidelines. Often, the acutely injured patient with documented anemia and hemodynamic instability post-operatively is transfused with the goal of rapidly restoring adequate intravascular volume and increasing oxygen delivery. This is done only after a thorough operative and radiographic search for active bleeding. There is limited evidence-based support for this practice, however, the question does not easily lend itself to study. Thus, the decision to transfuse should remain subject to clinical judgment.

In similar fashion to patients with cardiovascular disease, the appropriate trigger for transfusion in the hemodynamically stable trauma patient remains unclear. Some investigators have suggested that multiple-trauma patients may be particularly susceptible to the adverse effects of decreased oxygen transport resulting from severe anemia.(58) As mentioned previously, a subgroup analysis of the TRICC trial addressed the outcomes of critically ill trauma patients transfused according to a restrictive strategy versus a liberal strategy.(48) Importantly, this study included patients with all types and anatomic locations of trauma, including penetrating trauma and traumatic brain injury (TBI). The comparison showed that there was no statistically significant difference in 30-day mortality, presence of multiple organ dysfunction, length of ICU stay, or duration of hospitalization between the two groups. They concluded that a restrictive transfusion strategy, again defined as a trigger of 7.0 g/dL with a goal hemoglobin level of 7.0–9.0 g/dL, was same for critically ill multiple-trauma patients.

Transfusion in TBI Patients

Transfusion in multi-system trauma patients is further complicated by differing opinions in management by various sub-specialists involved in their care. One particular area of controversy is the goal hemoglobin in patients with TBI. Modern neurological surgery text books still suggest the need to maintain a hematocrit above 30% to preserve oxygen delivery in TBI patients.

(59) Studies in dogs have suggested that a worsening metabolic response occurs in animals with TBI that are exposed to chronic anemia.(60, 61) These findings have not been corroborated in human studies, and little empiric evidence exists to support a higher transfusion target. One study looking at cerebral tissue oxygenation in patients with subarachnoid hemorrhage did show an improvement in oxygen delivery in most patients, however, over 25% of the patients in the study actually had a decrease in tissue oxygenation associated with transfusion.(62) The clinical significance of these findings is unclear.

Two additional studies contradict the need for a higher transfusion trigger in TBI patients. In a retrospective review of patients with severe TBI, a significant benefit was identified in the group of patients who were maintained for a prolonged period at a hematocrit below 30%.(63) Additionally, transfusion of blood was associated with worsening short-term outcomes. Furthermore, subgroup analysis of the TRICC trial assessed patients with moderate-to-severe TBI for outcomes in the restrictive versus liberal transfusion strategies. Again, no difference was identified between the two groups, suggesting that the transfusion trigger for patients with TBI should not differ from that assigned to all critically ill patients.(64)

THE ROLE OF ERYTHROPOIETIN

Multiple adjuvant therapies to minimize the need for RBC transfusion in critically ill patients have been proposed. The role of administration of erythropoietin has recently been studied by multiple investigators. Abnormally low levels of erythropoietin as well as depressed iron stores have been documented in trauma patients, and some have postulated that this is due to the effect of inflammatory cytokines on renal production of erythropoietin. (65) Two large, multi-centered, randomized controlled trials conducted in critically ill patients showed that administration of high doses of erythropoietin resulted in an overall decrease in the odds of receiving transfusion.(6, 66) Although significantly fewer units of blood were transfused, there was no significant difference in outcomes in terms of mortality, MOF, or length of stay observed in patients who received erythropoietin in an ICU setting.(6)

These findings were contradicted in a more recent randomized, double-blind, placebo-controlled multi-center trial which showed that administration of erythropoietin was not associated with a decreased rate of transfusion.(67) Interestingly, this study did show a survival advantage in the subgroup of trauma patients, however, it also showed an increase in thromboembolic events in this study population. The difference between these studies with conflicting outcomes in rates of transfusion after erythropoietin may be attributable to a change in transfusion practice between the two studies. In the more recent study showing no decrease in odds of receiving transfusion, the patients were transfused at a mean hemoglobin of 8.0 g/dL, which was lower than the mean pre-transfusion hemoglobin of 8.5 g/dL used in earlier studies. (6) The finding of decreased mortality in trauma patients is also supported by recently presented data analyzing the trauma subsets of two large randomized studies.(68) In summary, the role of erythropoietin in critically ill patients remains under scrutiny, although the data suggests that a survival benefit may exist in

trauma patients. Further study to determine the optimal patient population, timing of administration, and cost-effectiveness of erythropoietin are warranted.

> The prior patient developed hypotension and was transfused two units of PRBCs. He is noted to be febrile after the transfusion, and 6 h later, he develops respiratory failure, refractory hypoxemia on the ventilator, and frothy exudates from the endotracheal tube. A diagnosis of Transfusion Related Acute Lung Injury (TRALI) is made.

Transfusion-Related Acute Lung Injury

TRALI is one of the most important causes of morbidity and mortality related specifically to transfusion. The exact etiology of this clinical syndrome is unknown, although animal studies suggest that donor-derived anti-leukocyte antibodies such as anti-HLA class I and II, as well as anti-granulocyte antibodies may be implicated.(69) Previously, the lack of a standardized definition of TRALI made clinical investigation difficult. A recent expert consensus panel has proposed the following definition:

"The major concept is that TRALI is defined as new acute lung injury occurring during or within 6 hrs after a transfusion, with a clear temporal relationship to the transfusion. Also, another important concept is that acute lung injury temporally associated with multiple transfusions can be TRALI, because each unit of blood or blood component can carry one or more of the possible causative agents: antileukocyte antibody, biologically active substances, and other yet unidentified agents".(70)

Using this definition, recent prospective data suggest that the incidence of TRALI may be as high as 8% in critically ill patients receiving blood transfusion.(69) Others have defined the incidence to be 1 in 5,000 units.(71) TRALI is characterized by acute dyspnea or hypoxemia which may be associated with acute labile blood pressures and acute leucopenia. Treatment is primarily supportive and blood from the same donor should be restricted from future transfusion. TRALI has been associated with increased mortality by many authors and is now the leading cause of transfusion-associated mortality.(70, 72, 73) Blood from multiparous female donors has been implicated as leading to higher rates of TRALI.(69) Massive transfusion is also strongly associated with development of acute lung injury.(74)

CONCLUSION

Anemia is a ubiquitous problem in the ICU, and the decision regarding the timing of transfusion is almost certainly a daily event for the intensive care physician. Additionally, surgeons face the challenge of overcoming previously defined liberal transfusion triggers in their post-operative patients with anemia. As such, a thorough understanding of the risks and benefits of transfusion is absolutely critical for every surgeon and surgical intensivist. Historically, the poor outcomes associated with anemia were addressed with aggressive transfusion to an arbitrary hemoglobin

value, often ranging from 10.0 to 12.0 g/dL. The current literature suggests that the hemodynamically stable patients should be transfused with a trigger of 7.0 g/dL and a goal level post-transfusion of 7.0–9.0 g/dL, although certain subgroups, particularly the elderly with active myocardial infarction, may benefit from higher levels. Despite excellent evidence to support these values in multiple subgroup analyses, studies suggest that the collective practice in ICUs worldwide has not changed to be in complete compliance with the guidelines. Reasons for the resistance to change by current clinicians are unclear, however, the abundance of literature suggesting increased rates of infection, MOF, and death with blood transfusion provided should serve as a powerful influence on surgeons and intensivists in training. Timing of transfusion as well as the use of adjuncts such as erythropoietin and leukoreduced blood remain controversial and are important areas for future research. Blood transfusion is an important tool in the resuscitation of anemic critically ill or postoperative patients, however, it should be used with caution and with an eye toward the associated potential morbidity and mortality.

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36 Nutritional considerations in the surgical intensive care unit
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A 60-year-old man is admitted to the intensive care unit (ICU) after sustaining the following injuries in a car crash: bilateral pulmonary contusions, right flail chest, grade 3 liver lacerations treated non-operatively with angiographic embolization, and a right femur fracture. He is intubated and is on mechanical ventilation. His past medical history is significant for hypertension only. He was otherwise healthy.

HISTORY OF NUTRITION IN MEDICINE

The importance of nutrition in the management of critically ill patients has been known since the advent of modern medicine. Carl von Voit, a German chemist and physiologist in the late 1,800s, diligently examined, documented, and commented upon the importance of protein, fat, and carbohydrates on metabolism. He observed that dogs were maintained on a protein diet alone; with addition of fat to the diet, it led to increased fat stores. Furthermore, he noted that carbohydrates were preferentially oxidized for energy regardless of volume administered. Moreover, he noted that carbohydrates protected from fat loss. Most importantly, von Voit observed that protein was metabolized most easily, then carbohydrates, and then fat.(1) As a result, he is frequently considered to be "the father of modern dietetics." The association and significance of von Voit's work to the predominant notions of nutritional support and management of critically ill patients today cannot be overstated.

GENERAL OVERVIEW AND INITIAL ASSESSMENT

Upon presentation to the ICU, the nutritional status of the patient should be considered in light of the reason for admission. In almost all cases, the reason for critical illness was not related to nutrition, but instead to injury or some acquired illness; therefore, the reason for admission was not a nutritional disease per se. For this reason, most initial urgent treatment decisions should be focused on the presenting illness. However, once these are made and are being implemented, delivery of nutrition is very important to prevent nutritional complications for those with prolonged stays; those in the SICU for more than 48 h are at great risk for nutritional complications if this aspect is neglected. Therefore, nutrition has, and always will, have a spotlight in the prolonged care of surgical patients. In fact, significant evidence exists that the implementation of nutritional support algorithms in the ICU result in patients reaching caloric goals more quickly and thus minimizing complications (2), and in turn, these patients have improved clinical outcomes.

In considering nutrition, the first order of business upon admission to the ICU is to assess the underlying nutritional status of the patient and the breadth and location of injuries and illness. The baseline nutritional assessment involves clinical consideration of any pre-existing medical conditions such as diabetes mellitus, previous dietary, and activity habits, and potential for nutritional deficiencies such as those common with alcoholism. Next, the patient should be examined for evidence of nutritional vitamin or mineral deficiencies, and then for long-term pathologic conditions associated with substrate utilization, such as emaciation or obesity. Then, acute anatomic and physiologic changes associated with the nature of the operation(s) and/or traumatic injuries that the patient has sustained must be considered. From these assessments, some notion of specific nutrients that should be provided in addition to those typically given is attained.

The next goal is to predict the patient's ICU course. Frequently, this information is compiled by many members of the patient's care team, which typically consists of faculty who are eager to teach, residents who are eager to learn, clinical pharmacists, clinical nutritionists and dieticians, and occupational and physical therapists. In addition, oftentimes non-critical care consultants are involved in the care and are tasked responsible for performing treatments dramatically affecting the trajectory of recovery such as orthopedics or plastic surgeons. A cohesive and communicative team is very important to insure comprehensive understanding of the patient's condition, his or her expected trajectory of recovery, and thus an estimate of energy expenditure and requirements. Once the potential deficit(s) are predicted, the ICU team can assign an efficient and timely care plan to address the patient's nutritional requirements. Thus, it is only when his nutritional status is optimized that the patient will have the best chance to recover from his/her operations and/or injuries.

In our case, the patient has no pre-existing nutritional deficiencies or medical conditions affecting substrate utilization such as emaciation or obesity. Therefore, further considerations are only for the development of nutritional complications associated with his injuries. However, he will need operative fixation of the femur fracture which is scheduled for the next day, and it is expected that his ICU course will be a prolonged one associated with ventilator dependence from the severe pulmonary contusions. He is also at great risk for the development of multiple-organ failure.

Initial Considerations

Convincing evidence exists that early nutritional support improves clinical outcomes in the critically ill.(3) This is particularly true in those with severe traumatic brain injury (TBI). For example, consider the following findings in patients in those who receive early nutritional support:

- decreased 2 week mortality when fed within the first 7 days.
- decreased caloric intake was associated with increased mortality.

Furthermore, these data suggest that early nutrition may be just as important in patients with head injury to avoidance of hypotension and hypoxia.(4)

In patients with respiratory dysfunction, and especially those requiring mechanical ventilation, the importance of optimal nutritional status is evident. It is well known that patients on mechanical ventilation have significantly increased metabolic demands and thus energy requirements.(5) If these patients do not receive nutritional support the problem compounds as the patient becomes more metabolically deficient. Currently, the accepted early nutritional support strategy is to feed enterally as soon as possible, preferably within 24–48 h of admission to the Surgical Intensive Care Unit (SICU) to decrease infectious complications (6) and ICU length of stay. (7) Some studies have addressed mortality benefit, but none have showed a significant advantage to early enteral feeding.(8) However, there is evidence that the implementation of an early nutrition protocol decreases time on the ventilator by about 7 days.(9)

Patients with gastrointestinal dysfunction represent a potentially problematic group. While the advantages and disadvantages of enteral and parenteral nutrition will be discussed later, suffice it to say that initiating enteral nutrition in patients with gastrointestinal dysfunction can be quite problematic. Specifically, patients with bowel obstruction, ileus, inflammatory bowel disease, short bowel syndrome, or fistula are not candidates for early enteral nutrition. Additionally, patients who demonstrate gastrointestinal intolerance, most commonly manifested by high gastric residual volumes (> 250 cc) and diarrhea, are also less favorable candidates for enteral nutrition. However, patients with or without gastrointestinal dysfunction still benefit from early nutritional support as demonstrated by decreased SICU length of stay.(10)

In our case, the patient arrives to the SICU without severe head injury or gastrointestinal dysfunction. He has significant pulmonary injuries, including pulmonary contusions and rib fractures, requiring mechanical ventilation. He is in a state where energy expenditure can quickly escalate. As a result, early nutritional support is indicated. Furthermore, since he has no gastrointestinal dysfunction, initiating early enteral nutrition is the best choice. Early enteral nutrition in this type of patient has been shown to decrease time on the ventilator, decrease SICU length of stay, and improve the overall clinical outcome.

Calculating Energy Requirements

Prediction of energy utilization in critically ill patients depends upon pre-admission nutrition status, type and severity of injury or illness, post-operative status if applicable, and a prediction of the patient's SICU course. Traditionally, ICU teams initiate a nutritional support regimen that provides approximately 20–25 kcal/kg/day of non-protein calories and approximately 1–2 g/kg/day of protein intake based on recommendations from the European Society for Parenteral and Enteral Nutrition.(11) This can be significantly modified based upon the type of injury particularly for burns (12) and head injury.(13) In general, the above recommended energy delivery standards are adequate for most populations.

While a protein intake of 1–2 g/kg/day, adjusted for protein losses, appears adequate, there is a movement for adjusting the non-protein caloric intake based upon the chronicity of the patient's critical illness with the notion that prolonged courses in the ICU are associated with increased hypermetabolism and energy expenditure later in the course. For instance, some intensivists recommend a non-protein caloric goal of 20–25 kcal/kg/day during the initial acute phase of the patient's critical illness (approximately day 0–7). Then, they suggest that a non-protein caloric goal of 25–30 kcal/kg/day may be beneficial in the post-acute phase of the patient's critical illness (approximately day 8 onward).(11) While this rationale makes sense conceptually, there is no overwhelming clinical evidence to support its widespread adoption as yet.

Our patient is admitted to the ICU with significant pulmonary, hepatic, and orthopedic injuries. He has no past medical history of malnutrition. However, his SICU course is one where his energy expenditure has the potential to escalate quickly, especially given his requirement for mechanical ventilation. Along those lines, there is a strong potential for exacerbated hypercatabolism. As a result, he would most likely benefit from a nutritional support regimen that consists of an enteral feeding formula with a non-protein caloric goal of 25 kcal/kg/day and a protein intake goal of 1.0 g/kg/day for the first 7 days. After the acute phase of his ICU admission (approximately day 7), if he is still intubated with regular visits to the operating room or other factors that may exacerbate his hypercatabolic state, he may benefit from increasing his non-protein caloric intake to approximately 25–30 kcal/kg/day. Of course, it is of utmost importance that the ICU team, which consists of dedicated nutritionists and dieticians, assesses his daily energy intake and expenditure so as to optimize his energy balance.

Initiating Nutritional Support

It is almost universally accepted that nutritional support should be initiated early in SICU patients. Delayed nutritional support has been associated with increased number of infectious

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complications and increased length of ICU stay and hospital stay as stated above. Additionally, there are some who recommend initiation of enteral nutrition within the first 24 h of admission to the ICU, and if enteral feeding is not feasible they recommend initiating total parenteral nutrition.(14, 15) Regardless, most still agree that enteral feeding is the preferred method of feeding in the critically ill for reasons of cost and decreasing infectious complications. That being said, it is difficult to establish and maintain caloric delivery goals in the critically ill for reasons of expeditions out of the ICU for procedures, holding feeds for increased gastric residuals, and pump malfunctions. These difficulties often lead to decreased caloric delivery.(16) However, some of these can be overcome with adherence to clinical guidelines for nutritional delivery in the ICU.(17) At this time, we recommend institution of enteral feedings as soon as feasible after arrival to the ICU. If these are not tolerated after a reasonable duration (e.g., 48 h), then institution of parenteral feeding should ensue to deliver indicated calories and protein.

The literature cited above is only a sampling of the overwhelming amount of literature that exists on this topic. Ultimately, however, nearly all reviewed studies recommend initiating nutritional support within the first 24–28 h of admission to the ICU. This is especially important in patients who are in a hypercatabolic state, such as burn and trauma patients (Table 36.1).

> In our case, the patient is a trauma patient with multiple injuries. Additionally, he is likely in a hypercatabolic state, especially since he is mechanically ventilated. Initiation of early nutritional support in this patient could potentially result in decreased amount of time on the ventilator, decreased number of infectious complications, decreased length of SICU stay, and decreased length of hospital stay. As a result, he would most definitely benefit from the initiation of enteral nutrition support within 24–48 h of his admission to the SICU.

Enteral Nutritional Support

There are two available types of nutritional support: enteral and parenteral. Currently it is well accepted that enteral feeding, if clinically possible, is the best means of administering nutritional support. Some of the benefits of enteral feeding

Table 36.1 ICU Populations Likely to Benefit from Early Nutritional Support.

- burn patients.
- chronically malnourished patients.
- trauma patients with no gastrointestinal tract injuries.
- immunodeficient patients.
- TBI patients.
- patients with significant comorbidities (such as chronic kidney disease or chronic obstructive pulmonary disease)

include provision of nutrients for gastrointestinal mucosal cells, decreased rates of infectious complications, decreased length of ICU stay, decreased overall hospital stay, and reduced costs.(18) Specifically, it is thought that enteral nutrition prevents intestinal atrophy and supports the immunologic functions of the gastrointestinal tract in critically ill patients. In fact, there are some who believe that the compromise of this "immunocompetent barrier" can result in pneumonia, sepsis, and multiple organ dysfunction syndrome.(19)

Despite its demonstrated and assumed benefits, there are several potential problems or barriers associated with enteral nutrition. Intolerance of enteral feedings is not infrequently encountered when administering enteral nutrition. Ileus is a commonly observed to cause intolerance of enteral feedings. The clinical manifestations of ileus include high gastric residual volumes, nausea, vomiting, abdominal distention, and aspiration. With regards to gastric residual volumes, there are several opinions. The volume of gastric residuals considered as high ranges from 150 to 300 cc, depending upon institutions and physicians involved.(18–20) For patients with high gastric residual volumes, the use of pro-motility agents and small bowel feedings has demonstrated some benefit.(21) Additionally, another clinical manifestation of enteral feeding intolerance is diarrhea which can be defined as more than six bowel movements in a day or more than 1,500 cc volume/day.(22) For these patients, the best option is to decrease the enteral feeding rate or decrease osmolarity. If this is unsuccessful, discontinuing the enteral feeding may be required to be replaced with parenteral nutrition. However, recent bowel management systems may alleviate some of the problems associated with diarrhea (23), and perhaps allow for continued tube feedings in spite of increased bowel movement episodes or high outputs in the absence of malabsorption problems. This can be tested by measuring reducing substances in the stool. It seems that most diarrheas that are encountered in the ICU are related to antibiotic use and not necessarily to enteral feedings.(24)

Other complications associated with enteral feeding include bowel ischemia and pneumonia. Bowel ischemia is especially problematic in patients who are receiving vasoactive pressor agents and thus enteral feedings are traditionally stopped on these occasions. Pneumonia associated with enteral feeding is possibly related to aspiration of gastric contents. Methods to avoid aspiration include elevating the head of the bed and carefully monitoring gastric residuals. Finally, there is some surprising evidence suggesting an increased risk of morbidity and mortality in patients receiving enteral nutrition. In fact, ICU patients with severe sepsis had a significantly higher mortality if they received enteral as opposed to parenteral nutritional support.(25)

Implementation of enteral feeding can sometimes prove to be problematic. This is especially true in patients who have had gastrointestinal dysfunction, manipulations, or operations. For example, patients with ileus, patients with diarrhea, or patients who have undergone recent gastrointestinal operations are usually not candidates for enteral nutritional support. There are examples, however, of patient populations who do well with enteral nutrition who traditionally were not fed in the past. In fact, there is some evidence that patients who previously were not candidates for enteral nutrition can be fed enterally with

minimal complications. Examples of these patients include those after esophageal surgery, those with intestinal perforation and peritonitis, those after colorectal surgery or abdominal aortic aneurysm surgery, and those with acute pancreatitis.(26)

In patients who are candidates, enteral nutrition should be initiated within 24–48 h of admission to the SICU. Otherwise, parenteral nutrition should be initiated. Traditionally, enteral nutrition is administered via nasogastric or orogastric access. For the most part, ICU patients tolerate feeding via a nasogastric or orogastric tube well. If patients require enteral nutritional support for greater than 2 weeks, a smaller diameter (6–12 French) feeding tube may be more comfortable. These smaller catheter tubes should only be placed after adequate aspiration of gastric contents has been performed with a nasogastric or orogastric tube (e.g., prior to intubation).

Not uncommonly, patients will demonstrate clinical manifestations of upper gastrointestinal intolerance. These patients will complain of nausea, if awake, or have vomiting, high gastric residuals, abdominal pain, abdominal distention, or aspiration. In these patients, feeding with post-pyloric tubes through nasoduodenal tube placement or surgical placement of a duodenal or jejunal feeding access is an option. Furthermore, some patients may have minimal or poor oral intake for an extended period of time. Thus, in patients who may require enteral nutritional support for 6 weeks or more, surgical placement of a percutaneous duodenal, or jejunal feeding access may be of benefit but must be weighed against the risk of bowel perforation or abdominal wall problems. In our practice, we find that surgical placement of tubes is almost never necessary unless the patient has a severe head injury and is not expected to make a reasonable recovery for months.

Recently, a new controversy has emerged in the administration of enteral feeding. Surgical intensivists are divided about whether to place feeding tubes in the post-pyloric position. To date, there is no overwhelming evidence that post-pyloric placement feeding provides any benefits. For example, enteral nutrition delivered directly into the duodenum or even the jejunum has not demonstrated decreased incidence or risk of aspiration. (27) A safe clinical guideline, therefore, consists of the following recommendations:

1. post-pyloric feeding has no clinical advantages over gastric feeding in most critically ill medical, neurosurgical, and trauma patients; early gastric feeding (within 24–48 h) with a nasogastric or orogastric tube is sufficient in most critically ill patients;
2. post-pyloric feeding is recommended in patients at high risk of aspiration, in patients undergoing major abdominal surgery, and patients who are intolerant of gastric feeding;
3. patients who are at high risk for gastroparesis should have a small bowel feeding tube placed intra-operatively;
4. patients who are likely to require tube feedings for several months should have a gastric tube placed intra-operatively or by endoscopy.

Finally, there is the issue of bolus versus continuous enteral feeding regimens for critically ill patients. Bolus feeding, also known as intermittent feeding, is enteral nutrition that is administered several times per day either via gravity or a pump. The timing of the feeds can be adjusted to allow the stomach to empty. The amount and frequency of each bolus is calculated based upon the patient's caloric requirements. Ultimately, it is thought that bolus feeds allow the patient's gastrointestinal physiology to resemble the normal eating and digestion patterns. Continuous feeding, on the other hand, is administered, as the name implies, continuously for 24 h/day. The feeds are administered via a pump. The patient's daily caloric requirements are calculated and administered equally over a 24-h period. Some evidence exists that patients fed with bolus enteral feeds reach their caloric goal earlier and are more likely to remain at goal when compared to patients receiving continuous enteral feeds.(28) However, these data should be further confirmed before this is to be implemented as standard clinical practice for logistical reasons. Thus, while it is conceptually true that bolus feeding is more physiologic and, by giving the stomach more time to empty, less prone to aspiration, there is no overwhelming clinical evidence to support its use over continuous feeding.

> The patient in our case does not have any contraindications for enteral nutritional support. Additionally, at the current clinical juncture, it is likely that he will not require nutritional support for more than 2 weeks. Furthermore, he has neither had any intra-abdominal operations nor are any planned. Thus, our patient will most benefit from nasogastric or orogastric enteral nutrition initiated within 24–48 h of his admission to the SICU. With regard to bolus versus continuous feeding, there is no overwhelming clinical evidence to support one over the other, and the practice of the center is to give continuous feeding.

Parenteral Nutritional Support

Historically, we are taught that parenteral nutrition, usually in the form of total parenteral nutrition (TPN), is a form of nutritional support that is provided to patients who will be unable to tolerate enteral nutritional support for a period of 7 days. It was in the 1960s that parenteral nutrition via central venous access was widely and enthusiastically implemented.(29)

It is accepted that nutritional support, especially in the form of enteral feedings, has the potential to improve ICU patients' clinical outcomes. However, the benefits and drawbacks to parenteral nutritional support are still being debated. For instance, it is traditionally accepted that TPN provides patients with the important nutrients, micronutrients, fluids, and electrolytes. Despite these assumptions, however, nutritional support in the form of TPN has not demonstrated significant benefits in terms of length of ICU stay, length of hospital stay, and overall clinical outcomes when compared to patients receiving enteral nutrition.(27) Furthermore, it may be that patients not only do not receive benefit from parenteral nutrition, but also overfed with parenteral nutrition that might itself be harmful.(30) In addition to no overwhelming data supporting the use of parenteral nutrition over enteral nutrition, strong evidence suggests that patients

receiving parenteral nutrition suffer from more infectious complications, typically line infections, as compared to enteral nutrition. This further demonstrates that with ICU patients who have intact gastrointestinal tracts and no contraindications, enteral feeding is the optimal choice.

Despite its drawbacks, there are times where parenteral nutrition is beneficial. Realistically, parenteral nutrition is better than no nutrition at all, especially in severely malnourished and critically ill patients. This assumption was validated in a study where patients who received parenteral nutrition had a significantly lower incidence of infectious complications and mortality when compared to patients who received intravenous fluids only.(14) Again, this observation tends to reinforce the largely historical notion that parenteral nutrition is better than no nutrition at all. Furthermore, as alluded to earlier, parenteral nutrition may be more beneficial than enteral nutrition in severely septic patients, especially in terms of mortality.(25)

Our patient was admitted to the SICU with no intra-abdominal injuries or any evidence of gastrointestinal dysfunction. With all his injuries, however, he is a patient who would likely benefit from nutritional support. With no evidence of contraindications, the best critical care strategy for our patient is to initiate early enteral nutrition in the form of tube feedings. Because of minimal evidence of its benefit combined with its potentially severe infectious complications, there is no role for parenteral nutrition in this patient at this time.

Special Nutritional Support Considerations

There are several unique scenarios where the decision to select enteral nutritional support over parenteral nutritional support, or vice versa, is not an easy one. Two such examples are patients who develop pancreatitis and patients who have high-output fistulas.

It is not uncommon to have abnormal pancreatic enzymes in critically ill patients. Abnormal enzymes can also be seen in SICU patients who have no radiographic abnormalities of their pancreas. However, when a patient develops abnormally high pancreatic enzymes that are trending upward, abdominal pain, abdominal distention, and high gastric residual volumes the threshold to suspect pancreatitis should be low. This clinical picture, especially if supported by radiologic evidence, should prompt the ICU team to confirm a diagnosis of pancreatitis and adjust the nutritional support regimen accordingly.

Historically, patients with pancreatitis have been treated exclusively with parenteral nutrition. The theory was, and still is to some extent, that enteral nutritional support can exacerbate the pancreatitis because of its stimulatory effects on pancreatic secretions. Thus, the recommendations were to stop enteral feeding and initiate parenteral nutrition until the patient's clinical picture improved.(20) More recently, however, it appears that enteral nutritional support via jejunal access is favored over parenteral nutrition.(31) This sentiment has been adopted primarily because of the previously discussed benefits of enteral feeding over parenteral nutrition. Furthermore, there is no overwhelming

evidence of the benefit of parenteral nutrition over enteral feeding.(32) Obviously, the patient's clinical picture must be re-evaluated frequently. If the clinical picture worsens with enteral feedings, the ICU team must decrease the tube feedings or stop them altogether and re-evaluate for the next best option for the patient's nutritional support.

The utility of fluid and electrolyte repletion, nutritional support, and the treatment of sepsis in patients with high-output gastrointestinal fistulas have been known for at least 40 years. In fact, their importance in the management of patients with gastrointestinal fistulas, especially high-output ones, cannot be over-emphasized. During this time, it became clear that the clinical outcome of patients without sepsis and the clinical outcome of patients with resolved sepsis improved significantly with the use of parenteral nutrition. As a result, parenteral nutrition became a mainstay in patients with high-output gastrointestinal fistulas.(33) In fact, the importance of parenteral nutrition in improving clinical outcomes was thought to be beneficial in patients with all types of gastrointestinal fistulas.(34)

Some evidence, however, suggests that enteral nutritional support may be superior to parenteral nutrition in patients with high-output gastrointestinal fistulas.(35) This is perhaps due to the benefits of enteral feeds on gastrointestinal mucosal growth and immune function. Of course, these benefits must be balanced with the risks associated with enteral nutrition in patients with high-output fistulas such as increased fistula output and more breakdown of the skin around the fistula. Thus, while patients with gastrointestinal fistulas were historically treated with parenteral nutrition alone, a select population of these patients may do well with enteral nutritional support either as a supplement or as a replacement. Currently, patients with controlled fistulas will likely benefit from the advantages of enteral nutritional support. However, if patients with gastrointestinal fistulas are not tolerating enteral feeds, the enteral feeds must be stopped and parenteral nutrition must be started.

Combination Nutritional Support

Recent literature suggests that a nutrition regimen consisting of enteral and parenteral nutritional supports may be of benefit. Obviously, this is only an option in patients who can tolerate enteral feedings. In those patients, circumstances may arise that cause significant lapses in consistent nutritional support because of voyages from the ICU to the operating theatre, radiology, etc. Furthermore, daily assessments of a patient's nutritional status might demonstrate deficits such as protein-energy deficits. It is in these particular patients that a supplemental parenteral nutrition might be of benefit.

It is apparent that both enteral and parenteral nutrition have well-studied benefits and drawbacks. Is it possible, then, that a combination of the two exists such that the benefits of both are maximized and the drawbacks of both are minimized? Conceptually, this theory does make sense and the answer to the above-proposed question is maybe... This has the potential to be especially true in patients in whom the ICU team predicts to have frequent lapses in enteral feedings or unreliable means of measuring gastric residual volumes, for example. Thus, it would appear that in cases where underfeeding is a problem in patients receiving enteral nutrition, supplemental parenteral nutrition may be beneficial.

Since this method of delivering nutrition is a fairly recent, there are no overwhelmingly convincing randomized controlled trials. However, some intensivists recommend that if enteral nutrition fails to meet the patient's nutritional needs within 72 h, supplemental parenteral nutrition must be initiated immediately so that the patient receives all protein and energy requirements by 96 h after admission to the ICU. Furthermore, they recommend de-escalation of the parenteral nutrition as the enteral nutritional support approaches the patient's nutritional support goals.(36) Again, conceptually this theory makes sense. However, further randomized controlled trials are required to obtain any specific clinical practice guidelines and recommendations. Of course, as is always the case in surgery, the risks and the benefits must be evaluated prior to initiating any treatment.

> Our patient would benefit most from enteral nutritional support, as discussed previously. However, he may also benefit from supplemental parenteral nutrition since he has the potential to experience lapses in his scheduled feedings. For example, his feedings would likely have to be held if he needs to go to the operating room for his femur fracture or a missed intra-abdominal injury. Moreover, if his liver laceration requires an interventional radiology procedure, his enteral feedings will have to be held. Furthermore, he has the potential to develop ileus and possibly experience aspiration. As a result, his nutritional status must be evaluated at least daily. And, if his nutritional goals are not being met by the 72 h mark, the SICU team must evaluate the risks and benefits of implementing supplemental parenteral nutrition in our patient.

Substrate Choice

For non-protein calories, choices must be made between carbohydrate and fat for the principal source of substrate, whether the feeding is given enterally or parenterally. Carbohydrate is generally the preferred choice of cells for oxidation and energy generation. In fact, energy needs can be completely satisfied via carbohydrate with the only fat required being some linoleic acid once a week to prevent essential fatty acid deficiency. Also, carbohydrate loading induces endogenous release of insulin that might then act as a protein-sparing hormone through stimulation of protein synthesis. Furthermore, fat infusions have not been shown to have any protein sparing effect.(37) This begs the question of whether fat then should be used at all in our feedings. A study showed in a critically ill population in a crossover design that a low-fat, high carbohydrate formula improved protein accretion compared to an isonitrogenous isocaloric high-fat, low-carbohydrate formula.(38) Therefore, we recommend choosing an enteral or parenteral formula that is low in fat. Volume considerations should be secondary, as fat is not well utilized in critical illness as described above.

Emerging Nutritional Support Complements

There are numerous new nutritional support adjuncts that have either been implemented already or will be implemented soon. Specifically among these adjuncts are immuno-nutrition, and the use of anabolic agents. The inclusion of each of these adjuncts in ICU nutritional support is yet to be widely accepted.

Immuno-nutrition is a term that refers to the addition of specific immuno-nutrients that have been shown to amplify immune cell response in vitro. These immuno-nutrients include arginine, fish oil, and RNA. Enteral diets containing these adjuncts were shown to decrease infections in some trials (39), however, a recent meta-analysis of all such trials showed no benefit to these type of diets (40), and thus are not recommended at this time.

Glutamine serves as an energy substrate for enterocytes and immune cells. The addition of glutamine to parenteral nutritional support formulas decreased incidence of infections (41) and improved 6-month survival in critically ill patients.(42) These data combined with others indicate that glutamine-enriched parenteral nutrition is probably indicated if this type of nutrition is used. However, for enteral nutrition, the results are mixed with the population with the most benefit being those with injury.(43) Enteral glutamine is much decreased in cost compared to the parenteral dipeptide, and given that the risk of its use is low with potential benefit, we recommend its use unless cost is a more pressing issue.

Arginine is known to provide anabolic and endocrine effects in some animal models. Additionally, it is a substrate for nitric oxide synthesis. Nitric oxide, in turn, is activated in several inflammatory conditions and has been involved in several immunological mechanisms. However, no studies to date demonstrate any advantages to arginine supplementation in the critically ill.

Omega-3 fatty acids are known to incorporate into the cell membrane and blunt the inflammatory process by producing prostaglandin E_3 and leukotriene B_5 which are less active compared to the omega-6 fatty acid-derived prostaglandin E_2 and leukotriene B_4. Omega-3 fatty acids have not been isolated from the other micronutrients and tested on a large scale in critically ill patients, however, two small studies seem to indicate some benefit, particularly for ARDS.(44, 45) As a result, like the other immuno-nutrients previously discussed, there is no overwhelming clinical data to support the widespread use of omega-3 fatty acid supplementation in the nutritional support formulas of critically ill patients.

For the purposes of this chapter, the final nutritional support topic to be discussed is the use of anabolic agents. Many such agents have been tested with the notion to convert catabolic patients to an anabolic state. While they may reach this point on their own, these therapeutic interventions can shorten the infirm period and improve recovery. The adjuncts can be broken into two major classes, soluble protein hormones and the anabolic steroids.

Soluble protein hormones consist of growth hormone, insulin, and insulin-like growth factor. Growth hormone was the first agent used clinically to ameliorate hypermetabolism after injury and illness. Gore et al. in 1991, using protein kinetics data measured in an isolated limb, showed that burned adolescents given growth hormone increased protein synthesis.(46) This study also showed that insulin, by itself, has a similar effect. However, enthusiasm for the use of growth hormone to treat hypermetabolism
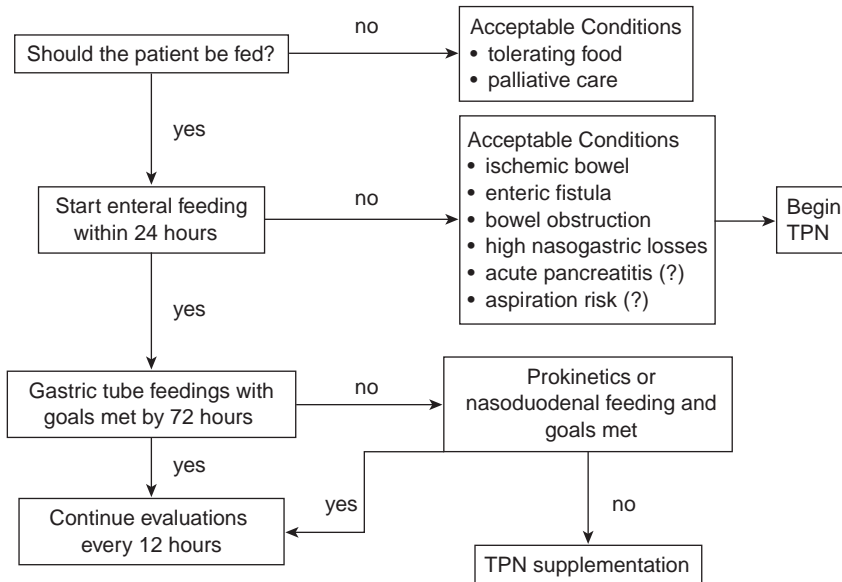
Figure 36.1 Algorithm for critical-care nutritional support.

was severely diminished by the findings of Takala et al. who demonstrated that the use of growth hormone in critically ill adults was associated with increased mortality.(47) Growth hormone has many of its actions through induced secretion of insulin-like growth factor. When this hormone is given by itself or with its binding protein, similar effects are seen from a metabolic standpoint (48), but, no real trials have been accomplished to show clinical benefit as of yet.

Insulin is the most potent anabolic hormone which improves muscle mass accretion in critically ill patients by stimulating protein synthesis.(49) When insulin was given as an anabolic agent throughout hospitalization in a population of critically ill children, lean body mass improved. This treatment is particularly relevant in light of the findings of van den Berghe, who showed that glucose control through insulin treatment and thus hyperinsulinemia improved mortality through reducing infections.(50) Effects on nutrition and lean mass were not evaluated. Questions are now being raised about how much "control" of hyperglycemia is enough? Because of the demonstrated improvements with insulin treatment without regard to glycemic control, it would seem that as much as possible would have the most benefit. This notion of course should be tested.

For the anabolic hormones, testosterone is the major androgenic steroid produced, and levels are extremely diminished after severe injury and illness.(51) When testosterone was given to severely burned men to normalize these levels, it was found that protein synthetic efficiency improved over 2-fold and protein breakdown decreased. The authors concluded that testosterone could be used to ameliorate muscle catabolism after injury.(52) Oxandrolone is an analogue of testosterone which has been used clinically and is purported to have a much greater anabolic potential than testosterone with a sixth of the androgenic effects. Many studies showed that oxandrolone use is safe and was efficacious when given to injured patients to improve net protein synthesis and nitrogen balance and decrease weight losses during critical illness.(53) Most recently, a multicenter trial on the use of oxandrolone in the severely burned

showed a decrease in acute hospital stay with its use without significant side effects. This was associated with a decreased number of operations for wound closure.(54)

Our patient, despite the seriousness of his injuries, is relatively uncomplicated. He has no evidence of gastrointestinal motility or absorption problems. As a result, he should do well with a normal, polymeric enteral nutritional support formula supplemented with glutamine. Because of lack of clinical evidence, immuno-nutrition is not indicated. Finally, our patient is still in the acute phase of his ICU admission. As such, and in light of potential side effects and complications associated with early use, there is no overwhelming clinical data to support the use of anabolic agents early in the course. However, after the hypermetabolic phase is established (5–7 days), he would likely benefit from oxandrolone 10 mg twice a day by mouth or tube as the risk is low until hospital discharge or thereafter.

SUMMARY

An analysis of the information presented results in an understanding of nutritional support and its relationship to the outcome of critically ill patients. Regardless of the injuries and disease states of the involved patients, nutritional support in the ICU is of utmost importance when planning the day-to-day care and management of critically ill patients. It is therefore crucial for the treating team to adequately and frequently assess their patients' energy and nutritional needs and creates a nutritional support regimen that is relatively easy to administer and manage (Figure 36.1). It is only in this way that critically ill patients will have the best opportunity to leave the ICU and, ultimately, go home.

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Pain, agitation, and delirium
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A 40-year-old intoxicated male is admitted to the ICU after sustaining a flail chest and pulmonary contusion in a motor vehicle crash. He is intubated and mechanically ventilated. In addition to his chest wall injury, he also sustained a large degloving injury to his right lower extremity. The patient was taken to the operating room by the trauma team for wound irrigation and debridement. He returns to the operating room post-injury day 1 for repeat washout and application of a negative pressure dressing. On post-injury day 2, the patient is placed on a spontaneous breathing (SBT) and awakening trial (SAT). During this time, the patient becomes increasingly agitated and has an increasingly hyperdynamic cardiovascular state. A rapid assessment is undertaken to rule out any life-threatening situations or obvious sources of acute agitation. The patient's status improves slightly after suctioning performed for increased amount of pulmonary secretions. Chest radiograph is negative for pneumothorax, but the right upper lobe is collapsed. The patient is somewhat dyssynchronous with the ventilator, the bladder catheter is patent, but the staff is unable to appropriately assess his pain (Confusion Assessment Method [CAM]-ICU positive, Richmond Agitation-Sedation Scale (RASS) +3). Unfortunately, the patient's peripheral intravenous access is removed by the patient and his respiratory status further deteriorates. Intramuscular lorazepam and haldol are utilized with adequate (temporary) sedation achieved. This allows a single peripheral venous line to be placed. The patient is sedated and paralyzed for therapeutic bronchoscopy with marked improvement in tidal volume and oxygenation. Additionally, a radial arterial line and subclavian central line are placed. Despite a deep level of sedation (RASS-4) achieved with bolus midazolam and generous fentanyl infusion for pain, the patient's cardiovascular status remains hyperdynamic (hypertension, tachycardia). Intravascular volume status is assessed and demonstrates adequate preload. The patient is felt to be at high risk for alcohol withdrawal syndrome (AWS) and is placed on the institution's alcohol withdrawal protocol Clinical Institute Withdrawal Assessment of Alcohol Scale (CIWA) with intermittent intravenous lorazepam.

Recent guidelines from the Society of Critical Care Medicine have reinforced the importance of attaining the goals of pain control and relief of anxiety and agitation.(1) Achievement of these end points is often viewed by patients and families with equal or greater importance than surgical technique or outcome. The inter-related nature of pain, anxiety, sleep, and delirium is frequently under-appreciated, poorly taught, and mismanaged, and the impact on patient outcomes is often incompletely understood.(2) Both analgesia and sedation are utilized to address each of these clinical parameters.

PAIN

How Should his Pain Be Assessed?

The level of pain reported by the patient should be considered the "gold standard" for both initial evaluation and response to analgesia.(1) However, the ability to consistently and systematically achieve adequate pain control is enhanced by utilizing quantifiable pain scales, particularly in the ICU setting where verbal communication is frequently hindered.(1, 2) These objective scales help to avoid the error of assuming "sedation equals analgesia."(2, 3)

For patients who can appropriately indicate pain, several one-dimensional reporting scales are available to evaluate the intensity of pain as well as the change in pain in response to intervention. These include the visual analog scale (VAS), the verbal rating scale, and the numeric rating scale (NRS) (Figure 37.1).(1, 2) The VAS is a well-validated tool that utilizes patient markings along a single horizontal line, with "no pain" on the left end and "worst pain imaginable" on the right end. The NRS uses a numeric scale of 0 through 10 to help patients rate their pain ("no pain" to "worst imaginable"). The NRS has the advantage of allowing both verbal and non-verbal documentations while providing a quantifiable number for assessment and compliance monitoring.

In the sedated, delirious, and/or intubated patient, physicians must often rely on objective clinical findings to guide care and analgesic administration. Tachycardia, hypertension, and tachypnea have traditionally been recognized as evidence of patient discomfort and pain; however, physiological signs have not shown reliable correlation with pain and may greatly underestimate its presence. Less than one-third of pain events are associated with abnormal vital signs in post-operative patients.(4, 5) Thus, the evaluation of both subjective "pain-related behaviors" (body movement, facial expressions) and objective parameters are often necessary.

What Modalities/Medications Should Be Used for Pain Control and How Should They Be Administered?

Opiates are the most common agents used for analgesia in the surgical patient and remain the gold standard.(1, 2) Respiratory depression may occur with all members of this class at higher dosing ranges and is more frequently observed when combined with benzodiazepines. Hypotension may occur after opiates as a result of reversal of endogenous catecholamine effects on vascular smooth muscle constriction. Thus, hypotension after opioid administration is more common in the patients with hypovolemia or in those already demonstrating cardiovascular collapse.(2)

VERBAL DESCRIPTOR SCALE (VDS)

no pain	*mild pain*	*moderate pain imaginable*	*severe pain*	*very severy*	*worst pain*

NUMERIC RATING SCALE (NRS)

0   1   2   3   4   5   6   7   8   9   10

no pain   *moderate pain imaginable*   *worst pain*

Figure 37.1 One-dimensional reporting scales to evaluate intensity of pain.

Table 37.1 Opioids for Acute Analgesia in Surgical Patients.

Opioid	Initial dosing	Half-life	Renal dosing	Hepatic dosing	Adverse events
Morphine	2–10 mg I.V. q2–6 h	3–7 hr	Reduce by 25–50% if CrCL<50	Not defined	Histamine release
Fentanyl	25–100 mcg I.V. q 1–2 h	1.5–6 hr	Reduce by 25–50% if CrCL<50	Not defined	Significant accumulation in fat, tachyphylaxis, rigidity with higher doses
Hydromorphone	0.2–0.6 mg I.V. q2–3 h	2–3 hr	Not defined	Not defined	Pancytopenia, agranulocytosis
Oxycodone	5–10 mg PO q4 hr	2–3 hr	Reduce by 25–50% if CrCL<50	Decrease initial dosing	Constipation, pruritus
Hydrocodone	7.5 mg PO q 4–6 hr	2–4 hr	Avoid with severe impairment	Avoid with severe impairment	Headache, pruritus

The duration of analgesia and tolerance of adverse effects with oral forms of opioids makes the enteral tract the preferred administration route. In patients requiring frequent dosing, sustained release options are available but should only be administered orally (not through naso-gastric or naso-enteric routes). In the acute setting, intravenous and epidural deliveries are often relied upon, and are discussed below (Table 37.1).

Morphine: Morphine is the most commonly prescribed of the opioids as it is well known, inexpensive, and has an excellent analgesic effect. It has a long duration of action allowing intermittent dosing to achieve adequate pain control. Morphine does, however, have several active metabolites that require renal clearance and its use in patients with renal failure increases the risk of toxicity and adverse event. In addition, morphine is associated with histamine release causing an associated pruritus.

Fentanyl: Fentanyl has a very rapid onset and a short duration, making intermittent dosing for continuous pain control problematic. It may be given to those with morphine allergies and does not cause histamine release. It does not have active metabolites requiring renal clearance and can be used safely in those with renal failure without dose adjustment.(1) Fentanyl has been shown to demonstrate tachyphylaxis in chronic exposure which may require significant increasing in dosing requirements or even change to other agents.(2, 3) Additionally, fentanyl is extremely fat soluble and demonstrates accumulation within repeated dosing. Fentanyl patches have shown adequacy in achieving pain control, but their use should be closely monitored and usually restricted to those with chronic pain issues.

Other opiates: Hydromorphone is similar to morphine in its duration and onset, but lacks active metabolites and the histamine release often seen with morphine. As such, it may be used in those with hemodynamic concerns and renal insufficiency. Meperidine has a significant side effect profile, with active metabolites that often lead to confusion, delirium, and even seizures, and for this reason it may not be given by constant infusion or at frequent intervals. Meperidine should be avoided for the management of acute pain in the surgical patient.(1)

NSAIDs provide analgesia through a non-selective, competitive inhibition of the cyclo-oxygenase (COX) enzyme, a critical component of the inflammatory cascade. Utilization of these medications may help reduce opioid requirements and is often adequate pain control for musculo-skeletal pain. Ibuprofen and

ketorolac are the most commonly utilized oral and parenteral forms of non-steroidal anti-inflammatory drugs (NSAIDs), respectively. (1–3) However, NSAIDs are associated with gastrointestinal (GI) bleeding, platelet inhibition, and renal insufficiency. The adverse renal effects are more common in those patients who are hypovolemic, elderly, or receiving the medications for an extended period. (1–3) Selective COX-2 inhibitors appear to be associated with less GI bleeding, but several have been withdrawn from the market by their manufacturers due to concern of increased risk of cardiovascular complications.(6) Though widely used as an over-the-counter analgesic, aspirin is also associated with GI bleeding and platelet dysfunction. Therefore, its use as an analgesic in the acute setting is fairly limited.

Acetaminophen is often utilized as a primary medication for mild-to-moderate pain and as an adjunct in more severe pain. When combined with an opioid, the two medications achieve an analgesic effect much greater than with the opioid alone. Overdose and subsequent hepatotoxicity may occur when combination agents are not recognized as containing acetaminophen. Daily administration of the total acetaminophen dose should be limited to less than 4 g. However, both alcohol abuse and malnutrition lower the threshold for hepatotoxicity. Care must be taken to limit dosing to less than 2 g in these patients.(1, 7)

Alpha-2 agonists (clonidine, dexmedetomidine) have been shown to be effective in primary and adjunctive control of pain and lack the side effect profile observed with opiates.(8) These agents are relatively lipid soluble and absorbed and distributed fairly quickly. Several mechanisms for their nociceptive effects have been debated, including spinal level inhibition of noradrenergic descending pathways and a reduction in pain perception.(1–3, 8)

Ketamine is a phencyclidine derivative with superb analgesic properties at sub-anesthetic doses that may provide excellent peri-procedural pain control without the development of respiratory depression, airway compromise, or hemodynamic deterioration.(1, 2, 9) However, its use may be associated with hallucinations, emergence "delirium," and aspiration; use should be limited to monitored settings.

Intravenous or epidural delivery: In patients requiring intravenous opioids, scheduled dosing (morphine, hydromorphone) or a continuous infusion (fentanyl, morphine) should be utilized to provide consistent analgesia. Though intermittent (as needed) regimens are often associated with inadequate pain control, excellent results (and superior patient satisfaction on pain scales) can be achieved through a patient-controlled analgesia (PCA) device.(2, 3, 10) Therefore, if the patient is capable of operating such a device, a PCA, utilizing morphine or hydromorphone, should be employed.(1) Neuraxial (epidural) anesthesia has been shown to achieve superior pain control following thoraco-abdominal procedures or trauma (rib fractures) compared to PCA.(10) Epidural analgesia has also been shown to decrease nosocomial pneumonia rates and shorten duration of mechanical ventilation. Catheter placement, however, is associated with hypotension, dural puncture, spinal cord injury, and urinary retention.(11)

Acute Pain Management in Patients with Opioid Dependence
The analgesic properties of methadone and buprenorphine differ quite considerably from those opiates utilized for acute pain. Additionally, tolerance and hyperalgesia associated with these agents likely diminishes any analgesic effect. Used alone, these agents

+4	Combative	Combative, violent, immediate danger to staff
+3	Very Agitated	Pulls or removes tube (s) or catheter (s); aggressive
+2	Agitated	Frequent non-purposeful movement, fights ventilator
+1	Restless	Anxious, apprehensive, but movements are not aggressive or vigorous
0	Alert and Calm	
-1	Drowsy	Not fully alert, but has sustained awakening to voice (eye opening and contact >10 seconds)
-2	Light Sedation	Briefly awakens to voice (eye opening and contact <10 seconds)
-3	Moderate Sedation	Movement or eye opening to voice (but no eye contact)
-4	Deep Sedation	No response to voice, but movement or eye opening to physical stimulation
-5	Unarousable	No response to voice or physical stimulation

Figure 37.2 Richmond Agitation Sedation Scale.

usually prove grossly inadequate in providing acute analgesia. As well, cross-tolerance between these medications and other opioids may explain why this population often requires higher and more frequent doses of opiates.(12, 13) Management should focus on delivering uninterrupted therapy (to address baseline opioid requirements) and aggressive pain management strategies (to achieve acute analgesia). Similar to managing opioid naïve patients, strategies should employ non-pharmacologic and non-opioid interventions as well. (14) Though physicians are often concerned that opioid administration in treating acute pain will result in relapse to active drug use, there is no evidence to support this bias.(12–14)

SEDATION
In the absence of adequate control of anxiety and agitation, achievement of other objectives and therapeutic end points is greatly impaired.(1, 3, 15) Anxious or agitated patients are more likely to remove feeding tubes, bladder catheters, and endotracheal tubes, resulting in loss of nutritional support, trauma, and potential airway complications. However, unresponsive, comatose patients are often the end result of "overshooting" sedation and this is equally detrimental. As such, the delicate balance of sedation and agitation is often difficult to achieve and even more difficult to teach to those in training.

HOW IS THE NEED FOR SEDATION ASSESSED?
Scales such as the Riker Sedation-Agitation Scale and Ramsay Scale have been developed to address this problem and are in wide use in many ICUs and hospitals. However, the RASS is the only scale demonstrated to be a valid and reliable tool for measuring the sedation-agitation levels over the patient's hospital course (Figure

Table 37.2 Sedative Agents for Intermittent and Continuous Administration.

	Initial dosing	Half-life	Adverse events/comments
Diazepam +	2–5 mg I.V. q 4–6 hr	20–80 hr	Active metabolites that may produce quite prolonged sedation
Lorazepam* +	0.5 mg–1.0 mg I.V. q 4–8 hr	6–8 hr	No active metabolites
Midazolam* +	1.0 mg/hr I.V., titrate for desired RASS	2–3 hr	Hypotension, significant respiratory depression
Dexmedetomidine +	0.2 mcg/kg/hr I.V., titrate for desired RASS	1.5–2 hr	May load with 1.0 mcg/kg I.V., but beware hypotension, bradycardia; do not exceed 24 h infusion
Propofol	5 mcg/kg/min, titrate by 5–10 mcg/kg/min for desired RASS	3–12 hr	"Infusion syndrome" seen with doses > 80 mcg/kg/min; hypotension, apnea; fatty tissue distribution may prolong effect

* Reduce dose with renal failure.
+ Reduce dose with hepatic insufficiency/failure.

37.2). (16) The RASS utilizes the duration of eye contact following verbal stimulation as the primary method of assessment and means of titrating sedation. Similar to the Glasgow Coma Scale, the RASS separates verbal and physical stimulation to allow for better grading of arousal levels.

What Modalities/Medications Should Be Used for Sedation and How Should They Be Administered?

Benzodiazepines may be used to provide brief procedural sedation, anxiolysis, or a continuous sedated state. Though they lack any actual analgesic effect, their impact on reducing opioid requirements by attenuating anticipatory pain is well documented. In addition, some drugs in this class (most notably midazolam) carry potent antegrade amnestic effects. Elderly patients and those with hepatic or renal insufficiency are most likely to experience adverse events from these agents. Respiratory depression, slurred speech, nystagmus, and obtundation are but a few side effects of this class. Additionally, these agents may contribute to delirium particularly in the elderly population, and in these populations consideration of their use must be balanced by the potential to lead to prolonged delirium.

The most common agents used for sedation are midazolam and lorazepam. Lorazepam has a longer half life and can be given by both intermittent and continuous administration to achieve continuous sedation; however, midazolam's short half-life usually mandates continuous infusion to achieve continuous sedation. Midazolam has a significant propensity for tachyphylaxis requiring escalating dosages.

Intermittent administration: In patients with baseline anxiety or persistent benzodiazepine requirements, use of intermittent (but scheduled) enteral diazepam or lorazepam is preferred. An as needed approach is preferable in the hospitalized patient requiring occasional dosing for illness-related stress and anxiety (Table 37.2).

Continuous infusions: In patients requiring frequent repeat dosing, utilization of a continuous infusion may be preferred and offer smoother titration and maintenance of RASS targets (see below). Midazolam should be used for continuous infusion as it has a fairly rapid onset and much shorter half-life than other benzodiazepines. However, its active metabolites may result in prolonged sedation in those with renal insufficiency.

ALCOHOL WITHDRAWAL SYNDROME (AWS)

AWS presents along a wide, varied presentation, both in depth and in intensity. Its often characterized by tachycardia, hypertension, confusion, altered level of consciousness, and often seizures.

To treat AWS, medications can be administered using fixed-schedule or symptom-triggered regimens. With fixed schedule regimens, benzodiazepines are administered at specific intervals, with additional doses given based on severity of symptoms. Other therapies include using ethanol itself as a continuous infusion (5–10% ethanol infusion initiated at 0.5–0.8 mL/kg ideal body weight/hour).(17) Once symptoms develop, however, rapid control of acute agitation is best controlled by use of intravenous lorazepam (2–4 mg) or diazepam (5–10 mg), titrated to severity of symptoms.(17, 18) As with other withdrawal states, clonidine (0.1–0.3 mg oral or per tube (PO/PT) every 8 h) has been successfully employed to prevent, decrease severity, and shorten duration of AWS.(18)

Despite these interventions and general improvement in his ventilator status, he requires increasing doses of medication to achieve sedation and is placed on a benzodiazepine infusion. On post-injury day 4, he is noted to be markedly sedated (RASS-4) to achieve control of his sedation and AWS end points. Over the next 24 h, he is successfully transitioned from a lorazepam infusion to dexmedetomidine. During this time, the patient's hyperdynamic state improves and he is maintained effectively at a RASS of −2. It has been 48 h since placement of his wound management system and the team makes a decision to change the negative pressure dressing at the bedside. Given the improvement in sedation levels with discontinuation of the benzodiazepine infusion, ketamine is chosen for bedside procedural analgesia and sedation. In light of his response to dexmedetomidine and reduction in p.r.n. dosing of benzodiazepines, the patient is started on enteral clonidine and the dexmedetomidine weaned off in the subsequent 24 h.

Sedation: Alternatives to Benzodiazepines

Propofol is an intravenous general anesthetic agent whose sedation properties can be achieved at lower doses. The rapid onset and short duration of action make this drug a preferred agent in many clinical settings, including those requiring frequent neurological assessments. It may be used as a continuous infusion, with initial achievement obtained through bolus administration. Propofol provides similar depth and quality of sedation to midazolam but demonstrates quicker extubation and recovery times.(19) Adverse events are

primarily related to duration of therapy (pancreatitis, hypertriglyc-eridemia, lactic acidosis); therefore, propofol use should be limited to 48 h or less. Additionally, propofol has no analgesic properties and should be administered in conjunction with opiates.

Selective alpha-2 adrenergic receptor agonists exhibit sedative, analgesic, and anxiolytic effects.(20) These agents maintain adequate sedation with less risk for producing hemodynamic instability or respiratory depression. Dexmedetomidine has the added benefit of analgesia (with less opiate requirements) and lacks the respiratory depression seen with propofol.(20) In a double-blind, randomized controlled trial, members of our multidisciplinary critical care group have demonstrated dexmedetomidine is actually more effective than lorazepam for achieving sustained sedation of mechanically ventilated patients. This was achieved with more days alive and without delirium or coma, and with significantly higher accuracy at meeting sedation goals.(21) When employed in settings where other agents have been unsuccessful (but the patient is successfully controlled with dexmedetomidine), we transition these patients to clonidine. In our experience, enteral (0.1–0.3 mg three times daily) and or transdermal clonidine (0.1–0.3 mg patch) help maintain light sedation and agitation control in those responsive to dexmedetomidine. Clonidine has also been shown to prevent, decrease severity, and shorten duration of AWS.(18) Adverse events associated with its use include hypotension, hypertension, severe bradycardia, and other arrhythmias.

What Is a Sedation Vacation? Is EEG Monitoring Necessary?

Continuous sedative infusions result in delayed awakening that appears to increase ICU stays through prolonging time on mechanical ventilation. Several studies have noted a reduction in ICU length of stay and mechanical ventilator days with daily interruption of sedation.(22–24) Daily spontaneous awakening trials (SAT) involve the interruption of sedating medications until the patient is awake and responsive to commands or until the patient becomes agitated. Not surprisingly, such trials have been met with resistance as some physicians question the feasibility of performing daily "SATs" in their ICUs and because of concerns of long-term psychological effects. However, these trials have actually been associated with a lower risk for post-traumatic stress disorder.(23)

Monitoring the progressive changes in sedation can be difficult. RASS utilizes the duration of eye contact following verbal stimulation; however, this is often unavailable as the patient is chemically paralyzed. For this reason, some authors have advocated the use of sedation monitoring such as Bispectral Index and others. Unfortunately, these monitoring devices have not reliably been able to distinguish levels of sedation in the intubated, critically ill patient.(25)

By post-injury day 6, the patient has become increasingly more awake and is following commands. He is, however, febrile, has a leukocytosis, and his chest radiograph demonstrates a right-sided infiltrate. The patient undergoes a diagnostic bronchoscopy and is started on presumptive treatment for ventilator-associated pneumonia. While his SAT have been successful, his spontaneous breathing trial (SBT) have

failed as he has become increasingly dyssynchronous with the ventilator. Transition from pressure-support mode to SIMV and assist-control only increase his dyssynchrony. Recruitment maneuvers (brief, sustained high PEEP) have met with improvement in oxygenation and even tidal volume. Given these findings, the patient is placed on airway-pressure release ventilation (APRV, bilevel) with resolution of his dyssynchrony and avoidance of deep sedation and chemical paralysis.

Avoiding Deep Sedation and Paralysis

Limiting sedation and neuromuscular blockade in critically ill patients, especially those receiving mechanical ventilation, is important and beneficial. APRV and bilevel are unique modes in that they allow for a prolonged inspiratory phase without requirements for heavy sedation and paralysis, and as such may improve long-term outcomes and facilitate weaning. APRV and bilevel provide improved gas exchange, cardiac output, and organ blood flow stimulated by increased spontaneous breathing (SBT) efforts.(26) While the supporting studies had their limitations, these ventilatory techniques are associated with decreased ICU days, decreased ventilator days, and lower use of vasopressors. Moreover, the use of paralytics and sedatives is markedly lower with these modes of ventilation.(27, 28) When utilizing these techniques to avoid the need for paralysis, it is crucial to closely monitor tidal volumes to ensure continued lung-protective inspiratory efforts.

When Paralytics May Be Required

Should neuro-muscular blocking agents (NMBA) be needed, the ventilator methods preferred at our institution includes pressure control and pressure-regulated volume control. With these modes, management strategies used include maximizing PEEP for inflection point, and if needed increasing I to E ratio. However, the choice of ventilator mode is site specific and more dependent on the comfort level of the ICU physician. For this reason, the exact mode chosen is less important if the principles of low Vt, permissive hypoxia-hypercarbia, and recruitment are employed as mentioned above.(29–31)

How Should They Be Administered?

Several options exist for NMBA use in this setting. Vecuronium is an intermediate-acting IV administered NMBA which produces blockade within 90 s and typically lasts 30 minutes. Following bolus administration (0.1 mg/kg), an infusion should be given (0.8–1.2 g/kg/min).

Because up to one-third of this agent is renally excreted and up to half is excreted in bile, other agents such as cisatracurium should be considered in patients with renal or hepatic insufficiency. Cisatracurium is an intermediate-acting NMBA that is metabolized by ester hydrolysis and Hofmann elimination, so the duration of blockade should not be affected by renal or hepatic dysfunction. In addition, it produces few, if any, cardiovascular effects. Bolus doses of 0.1–0.2 mg/kg result in paralysis in approximately 2–3 minutes and last approximately 20–30 minutes. Maintenance infusions of cisatracurium should be started at 2.5–3 g/kg/min and titrated accordingly.

Table 37.3. Agents Utilized for Agitation and Delirium.

	Initial dosing	Half-life	Adverse events/comments
Haloperidol	2–5 mg IM/IV*; double dose until effect achieved; use effective dose (PO) scheduled q 6 h	21–24 hr	Neuroleptic malignant syndrome (NMS), akathisia, tardive dyskinesia, arrhythmias
Olanzapine	2.5–5 mg IM (or 5–10 mg PO/PT) q 2 hr prn; if effective, start 2.5–5 mg PO/PT qhs	21–50 hr	NMS, akathisia, tardive dyskinesia, severe hyperglycemia
Risperidone* +	0.5 mg–1 mg PO/PTq 6 hr prn, then use effective dose q 12 hr	20–36 hr	Available as dissolving tablet; NMS, akathisia, tardive dyskinesia
Quetiapine +	25–50 mg PO/PT q 4–6 hr prn, then use effective dose q 12 hr	6–8 hr	NMS, tardive dyskinesia, QTc prolongation, headache, severe hyperglycemia, hyperlipidemia
Ziprasidone	10–20 mg IM q2–4 prn or 20 mg PO/PT q 4–6 hr prn, then use effective dose q 12 hr	6–8 hr	NMS, tardive dyskinesia, QTc prolongation, headache, akathisia

* Half dose with CrCL<50; half dose and use qd with CrCL <10.
+ Half dose and use qd with severe impairment.

How Should NMBA Be Monitored?

If patients receive NMBA, they should be assessed both by clinically and by "train-of-four" twitch monitoring, with a goal of titrating to achieve one or two twitches. (32) Before initiating NMBA, adequate analgesia and sedation (measured by RASS −4 to −5) should be achieved. Additionally, there are concerns of any sustained use of NMBA in the critically ill patient, including the risk of generalized deconditioning, skin breakdown, and prolonged muscle weakness.

> On hospital day 8, the patient is transitioned from APRV mode back to pressure support without incident. However, on the following day, he becomes agitated and confused and ICU-associated delirium is suspected.

As before, a rapid assessment should begin with ruling out any life-threatening situations. Many of these conditions (tension pneumothorax, occluded endotracheal tubes) can present with severe agitation and mental status changes and should be excluded first. Simultaneously, the patient should be protected from harming themselves through falls, self-extubation, and tube removal. Identifying and correcting less life-threatening issues should follow; ruling out ventilator dyssynchrony, bladder catheter occlusion, un-addressed pain, or pending bowel incontinence (especially in patients unable to communicate).(3, 33) Once such diagnoses have been excluded, appropriate management of agitation can proceed.

What Modalities/Medications Should Be Used to Control Agitation and How Should They Be Administered?

Haloperidol is often utilized for the rapid control of the acutely and severely agitated patients. Initial dosing of 5 mg intravenously should be used and may be repeated every 10–15 minutes (usually with increasing dosages) until adequate control is achieved. (34) If intravenous access is lost or unobtainable, intramuscular use is also successful but likely to take longer to achieve results. Its side effect profile, however, has historically limited the enthusiasm for its use (Table 37.3). Concomitant use of benzodiazepines or benztropine decreases extra-pyramidal symptoms (EPS) in the acutely agitated patient.(35)

Atypical anti-psychotics have gained increased attention for use as alternative agents for management of acute agitation. In lower doses than that required for acute psychoses management, risperidone, ziprasidone, and olanzapine have been shown to be appropriate alternatives for treatment of acute agitation. (34, 35) Their safety profiles include lower incidence of EPS and better patient tolerance. Additionally, once agitation is under control, these agents can be changed to the enteral route for continued use until agitation has resolved. However, these agents carry equal, if not higher, risk of arrhythmias. As such, they have failed to demonstrate a superior safety profile to haloperidol in managing the acutely agitated patient.(33)

DELIRIUM

Delirium is a global disturbance of consciousness characterized by fluctuating mental status, inattention, and disorganized thinking. Delirium has been historically dismissed as an expected complication of the hospitalized elderly patient, and its impact on outcomes thought to be negligible. However, recent studies have shown that delirium is significantly under-diagnosed, not limited to the elderly patient, and is associated with a 3-fold higher mortality.(36, 37)

Assessment of Delirium

The Confusion Assessment Method for the ICU (CAM-ICU) tool is a valid and extremely reliable tool, taking an average of 60 s to perform. The CAM-ICU is comprised of four features: acute change or fluctuation in mental status (Feature 1), inattention (Feature 2), disorganized thinking (Feature 3), or an altered level of consciousness (Feature 4) (Figure 37.2). In patients who are medically, traumatically, or pharmacologically comatose (RASS of −4 or −5), CAM-ICU is not assessed due to lack of any response to verbal stimulation. In patients with RASS scores of −3 or higher, CAM-ICU should be utilized. To be diagnosed as delirious, the patient should have a RASS score of −3 or higher, with an acute change or fluctuation in mental status (feature 1), accompanied by inattention (feature 2) and either disorganized thinking (feature 3) or an altered level of consciousness (feature 4).

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                          │  Sedation Scale / Delirium Assessment │
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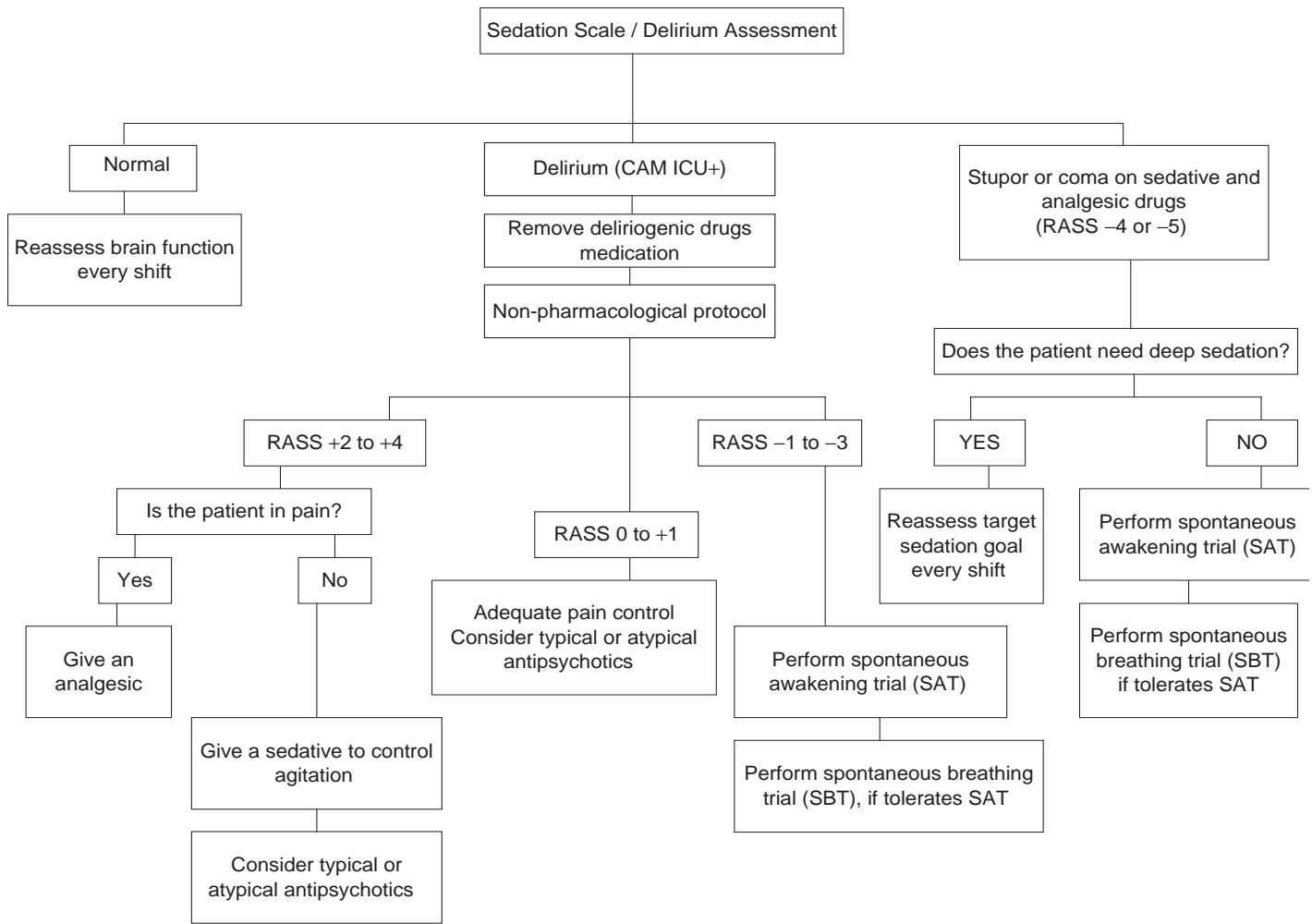

Figure 37.3 Evaluation and management of varying agitation and sedation in the ICU patient.

How Is This Treated?

With delirium, prevention is ideal. Avoiding high-risk medications, preserving sleep hygiene, and treating symptoms with appropriately targeted medications (i.e., opiates for pain, benzodiazepines for anxiety, anti-histamines for pruritus, not for sleep) are the foundations upon which one can hope to prevent delirium. Preserving or re-establishing the patient's senses (eye glasses and hearing aids) and providing sufficient daytime cognitive stimulation (through staff and family interactions) may help to prevent development of delirium, or at least shorten its duration and reduce symptom severity.

Initial treatment is aimed at reversing and/or treating any underlying medical conditions suspected of contributing to its development (Figure 37.3). After evaluating potential metabolic or infectious sources, all efforts should be made to remove "delirio-genic" medications. These include benzodiazepines, anti-histamines, anti-cholinergics (specifically diphenhydramine), and corticosteroids. Instituting daily interruption of sedatives and analgesics, and using these agents within a strict protocol, has both been shown to improve patients' outcomes.(22) Next, interventions focusing on environmental control, cognitive re-orientation, and "normalization" of clinical parameters should be implemented. Environmental control entails re-establishing sleep hygiene, through control of excessive

noise and staff disturbances at night and ensuring lights are on in the daytime and off at night.(38, 39) Sleep agents may be added to assist with sleep onset, depth, and duration. Increasing daytime communication with family and friends, increasing physical activity, and ensuring replacement of eye glasses and hearing aids is vital to achieving re-orientation of the delirious patient.(38)

Pharmacological intervention

Haloperidol: Haloperidol is the agent most often used at our institution as it has few anti-cholinergic effects, few active metabolites, and mild sedating side effects. It is available in oral and intramuscular forms, but we typically use it intravenously (although not FDA approved) because of its rapid onset and control of agitation.

Atypical anti-psychotics: In patients with enteral access, risperidone, olanzapine, quetiapine, and ziprasidone are available and have been used at our institution. These medications, however, often require titration to higher doses and increased frequency, but are associated (as with haloperidol) with arrhythmias, including corrected Q-T interval (QTc) prolongation and Torsades de pointes. Use of these medications has, in our experience, been associated with better tolerance of treatment and fairly quick return to the patient's baseline mental status.(40) Improved sensorium

and resolution of delirium symptoms appear to coincide with the re-establishment of the sleep–wake cycle. Unless delirium is felt to be the result of sedative or alcohol withdrawal, benzodiazepine monotherapy should be avoided.(22)

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Evidence-Based Recommendations for Evaluation and Management of Delirium in the ICU.

- As with pain and sedation, delirium should be routinely assessed in ICU patients, preferably with a validated scoring system such as the CAM-ICU. **(LEVEL 1B-strong recommendation, moderate-quality evidence)**

- Initial treatment is aimed at reversing and or treating any underlying medical conditions suspected of contributing to its development. **(LEVEL 1C- strong recommendation, low-quality evidence)**

- After evaluating potential metabolic or infectious sources, all efforts should be made to remove "deliriogenic" medications (benzodiazepines, anti-histamines, anti-cholinergics). **(LEVEL 1C)**

- Haloperidol is agent of choice should pharmacological intervention is required **(LEVEL 2C- weak recommendation low-quality)**; however, in patients with enteral access and without acute agitation, atypical anti-psychotics should be considered. **(LEVEL 2C)**

- Unless alcohol withdrawal is the suspected cause of agitation and or confusion, benzodiazepines should be avoided. **(LEVEL 1C)**

Evidence-Based Recommendations for Evaluation and Management of Pain in the ICU.

- Pain should be assessed on all patients, regardless of neurological examination or intubation status. **(LEVEL 1C- strong recommendation, low-quality evidence)**

- The patient's reported level of pain should be considered the "gold standard," preferably scored with objective visual scales. **(LEVEL 1C)**

- Morphine, fentanyl, and hydromorphone are relatively equivalent in their ability to achieve adequate pain control, though differences in side effect profiles, hepatic and renal clearance, and potency exist. **(LEVEL 1B- strong recommendation, moderate quality evidence)**

- In patients requiring intravenous opioids, scheduled dosing (morphine, hydromorphone) or a continuous infusion (fentanyl, morphine) should be utilized to provide consistent analgesia. **(LEVEL 1C)**

- Neuraxial (epidural) anesthesia has been shown to achieve superior pain control following thoraco-abdominal procedures or trauma (rib fractures) compared to patient controlled analgesia. **(LEVEL 1C)**

- Epidural analgesia has also been shown to decrease nosocomial pneumonia rates and shorten duration of mechanical ventilation. **(LEVEL 2C- weak recommendation, low-quality)**

Evidence-Based Recommendations for Evaluation and Management of Sedation in the ICU.

- Sedation should be provided only after ensuring adequate analgesia and treating reversible physiological causes. **(LEVEL 1C- strong recommendation, low-quality evidence)**

- Sedation/agitation levels should be assessed multiple times throughout the day with an objective, "bi-directional" scale such as the RASS. **(LEVEL 1C)**

- Patients should undergo spontaneous awakening trials (sedation interruption) at least one daily, where sedation is decreased to allow for appropriate neurological assessment. **(LEVEL 1A- strong recommendation, high-quality evidence)**

- In patients requiring frequent repeat dosing, utilization of a continuous infusion may be preferred and offer smoother titration and maintenance of RASS targets. **(LEVEL 2B- weak recommendation, moderate quality evidence)**

- Midazolam or dexmedetomidine are preferred for continuous sedation (LEVEL 2B), while lorazepam is the agent of choice for intermittent use. (LEVEL 2C- weak recommendation, low-quality) Propofol or dexmedetomidine are preferred in settings, where rapid awakening is important **(LEVEL 1C)**

38 Care of the potential organ donor
Carrie A Sims and Patrick Reilly

A 20-year-old male is transported to the ED after sustaining a gunshot wound to head. His Glasgow coma score is 3 and a head computed tomography (CT) reveals a transcranial trajectory. Neurosurgery is consulted and the injury is deemed "nonsurvivable." The patient is transferred to the ICU for further management. The patient's blood pressure is 90/50 mmHg, his heart rate is 115 bpm. His pupils are fixed and dilated, but he continues to have a gag reflex.

HOW IS BRAIN DEATH CLINICALLY DEFINED?

The definition of death has evolved from the cessation of cardiorespiratory function to that of irreversible brain damage. This change in attitude was officially reflected in the Uniform Anatomical Gift Act in 1968 which provided the legal framework for the process of organ donation.(1) The President's Commission in 1981, formalized the definition in the Universal Determination of Death Act stating that "an individual who has sustained either (1) irreversible cessation of circulatory and respiratory functions, *or* (2) irreversible cessation of all functions of the entire brain, including brainstem, is dead."(2) The Universal Determination of Death Act required physicians to determine brain death in accordance with national, regional, or local medical standards. Needless to say, despite the "universal" declaration, there is leeway for institutional inconsistencies. In a recent review of the *U.S. News and World Report* top 50 institutions for neurology and neurosurgery, Greer et al. (3) report marked variability in brain death determination with relatively poor conformity between guidelines regarding apnea testing.

The American Academy of Neurology has published guidelines to assist with the practical determination of brain death.(4) In order for the patient to be declared brain dead, there should be no clinical brain function and the proximate cause must be known and irreversible. Specifically, the patient must be warm (≥ 90 °F, but ≥ 97°F for the apnea test), medical conditions that may confound the clinical diagnosis must be excluded (e.g., severe electrolyte, acid–base, or endocrine disturbances), and there should be no drug intoxication or poisoning. Clinically, brain death is defined by coma, the absence of brainstem reflexes and apnea. The American Academy of Neurology (AAN) recommends specific physical tests in order to interrogate each of these variables (Table 38.1).

Appropriate medical record documentation of the criteria used to diagnose brain death is also required. The etiology and irreversibility of the condition resulting in brain death should be explicitly stated. The absence of brainstem reflexes and the lack of motor response should be documented. The apnea test should be recorded, specifically documenting the lack of respiratory effort and the results of the final arterial blood gas.

It is recommended that the patient undergo two clinical evaluations at least 6 h apart. Although not specifically stated in the AAN guidelines, we recommend that clinical brain-death evaluations be completed by two qualified physicians who are not part of a transplant team. Because brain death is a clinical diagnosis, confirmatory tests are not mandatory but may be desirable when specific components of the clinical testing cannot be reliably performed.

WHAT CONFIRMATORY TESTS CAN BE USED IN DIAGNOSING BRAIN DEATH?

Confirmatory tests are recommended when the clinical diagnosis of brain death cannot be made with certainty. For example, a definitive diagnosis of coma cannot be made in the setting of sedatives, neuromuscular blockade, tricyclic antidepressants, anticholinergics, antiepileptics drugs, chemotherapeutic agents, or toxic levels of aminoglycosides. Severe facial trauma, cervical spine injuries, or preexisting pupillary abnormalities may make interrogation of specific brain stem reflexes unreliable. Additionally, severe pulmonary disease with chronic CO_2 retention or sleep apnea can compromise the validity of the apnea test. In these situations, confirmatory tests can be used to support the diagnosis of clinical brain death.

Confirmatory tests used to support the diagnosis of brain death include electrophysiologic tests (e.g., electroencephalography and somatosensory evoke potentials) and cerebral blood flow studies. Because electrophysiolgic tests can be confounded by metabolic concerns, anatomic variability, and variations in inter-rater agreement, studies that evaluate cerebral blood flow are generally more accepted as standard practice. Cerebral blood flow studies provide objective confirmation of brain death precisely because the absence of cerebral perfusion is incompatible with brain viability.(5)

Intracranial blood flow can by evaluated by transcranial Doppler studies, cerebral angiography, and nuclear medicine scans. Of these three modalities, transcranial Doppler is the least expensive, but is the most technically challenging. Consequently, transcranial Doppler use has been associated with a fairly substantial false positive rate.(5) Cerebral angiography and nuclear medicine imaging, on the other hand, provide a more precise evaluation of perfusion and are not as operator dependent. Although once considered the "gold standard," cerebral angiography is rarely performed as the initial confirmatory study in the diagnosis of brain death. Because of its invasive nature and associated risks, cerebral angiography has been replaced by nuclear medicine techniques in most clinically settings.(6) Currently, [99mTc]-labelled hexamethylpropyleneaminoxime (HMPAO) rather than [99mTc] pertechnetate is used to assess intracranial perfusion. Unlike [99mTc] pertechnetate, [99mTc]-HMPAO penetrates the brain parenchyma in proportion to blood flow and is particularly helpful in demonstrating the presence or absence of brain perfusion. When used with single photon emission computed tomography, [99mTc]-HMPAO provides a multiplanar functional image of whole brain perfusion with excellent reliability.(7)

Table 38.1 Clinical Parameters for Determining Brain Death in Adults.

Cardinal Finding	Clinical Response	Physical Exam
Coma or unresponsiveness	No cerebral motor response to pain in all extremities	• Nail bed pressure • Supraorbital pressure
Absence of brainstem reflexes	Pupils unresponsive and fixed	• No response to bright light • Size: midposition (4 mm) to dilated (9 mm)
	Ocular movement	• Doll's eyes: No oculocephalic reflex • Cold calorics: No deviation of eyes to irrigation of each ear with 50 ml cold water *allow 1 minutes after injection and at least 5 minutes between testing each side*
	Facial sensation and motor response	• No corneal reflex to touch with swab • No jaw reflex • No grimacing to deep pressure on nail bed, supraorbital pressure, or temporomandibular joint
	Pharyngeal and tracheal reflexes	• No response to post. pharynx stimulation with tongue blade • No cough response with bronchial suctioning
Apnea Prerequisites: Core temperature ≥ 36.5°C Systolic BP ≥ 90 mmHg Euvolemia (positive fluid balance in previous 6 hrs) Normal arterial pCO_2 (≥ 40 mmHg) Normal arterial pO_2 (preoxygenate to ≥ 200 mmHg)	No respiratory movements x 8 minutes Arterial pCO_2 ≥ 60 mmHg (or ≥ 20 mmHg over baseline) **if systolic BP becomes ≤ 90 mmHg, O2 saturation < 90% or cardiac arrhythmias develop, immediately draw an arterial blood gas and reconnect patient to the ventilator**	• Preoxygenate • Connect pulse oximeter and disconnect ventilator • Deliver 100% O2, 6 L/min into trachea • Look closely for respiratory movement • Measure arterial blood gas after 8 minutes • Reconnect ventilator

Source: Ref(4)

Both computed tomographic angiography and magnetic resonance imaging/angiography (MRI/MRA) are newer technologies that may allow for the assessment of intracranial perfusion, but require further investigation. In 1998, Dupus et al. evaluated 14 clinically brain-dead patients using two-phase spiral CT. Seven of these patients also underwent conventional cerebral angiography with excellent concordance between the two modalities.(8) In a larger study, however, a divergence rate of 30.2% was noted between conventional and CT angiography with CT angiography demonstrating persistent cerebral perfusion in 13 of the 43 patients studied.(9) Similarly, although several small studies have reported using MRI/MRA as a reliable adjunct in the diagnosis of brain death, (10–12) further investigation comparing it to conventional angiography or nuclear medicine imaging is needed to validate its routine use.

In addition to providing clinical information, confirmatory studies may result in the more timely management of the potential organ donor and have been associated with improved organ procurement rates, decreased length of ICU stays, and reduced associated costs.(13) More importantly, having a definitive study to confirm the diagnosis of brain death may help the patient's family understand and accept the brain death diagnosis.

WHAT ARE THE BARRIERS TO DONATION AND WHAT SYSTEMS CAN BE INSTITUTED TO IMPROVE THE CONVERSION RATE?

Organ availability remains a major limitation to transplantation in the United States. In the past decade, the number of people needing organs has doubled, while supply of available organs has only increased by a third. As a result, more people die each year waiting for an organ transplant than those that ever receive one.(14)

The number of potential organ donors in the United States is estimated to be as high as 27,000 annually. However, only 15–20% of these patients become actual donors.(15) The disparity between the number of potential organs and those that are actually donated represents a complex problem. The decision to donate may be influenced by cultural and religious beliefs. Physicians caring for the potential donor may be uncomfortable or inexperienced in addressing issues of donation. Finally, many organs become unusable due to the inadequate resuscitation of the potential donor. Strategies aimed at addressing these barriers could dramatically increase the potential availability of organs for transplantation (Table 38.2).

Approximately one-fourth of potential organs are lost because of medical mismanagement. By instituting clinical practice guidelines, Jenkins et al. dramatically decreased medical failures prior to donation (13–0%), improved the donation consent rate (44 vs. 71%) and significantly increased the number of organs harvested per eligible donor (1.8 vs. 3.4).(13) Diligent and systematic management of the potential donor using goal-directed guidelines maximizes the number of healthy organs that can be recovered.(16)

Organ Procurement Organizations (OPO's) provide an invaluable resource when caring for the potential organ donor and their active involvement clearly improves donation rates.(17, 18) According to

Table 38.2 Failure to Donate: Causes and Remedial Strategies.

Causes	Remedial Strategies
Failure to recognize potential organ donors	• Develop continuous education • Develop hospital-based organ donation team (social workers, chaplains, OPO members, ICU staff)
Family Refusal	
– Family approached about organ donation by the primary team (perceived conflict of interest)	• Primary service informs family of death • OPO approaches family
– Family informed about death and approached by about organ donation at the same time (perceived conflict of interest)	• Temporally separate the discussion of death and the request for donation • OPO should approach the family regarding donation
– Low acceptability of organ donation by minorities	• Understand and respect cultural diversity • Culturally sensitive education and outreach
Failure to expedite diagnosis of brain death	• Create clear guidelines for the diagnosis of brain death
Failure to maintain organ homeostasis	• Optimize organ perfusion using UNOS guidelines • Use lung protective strategies • Anticipate and treat endocrine abnormalities

OPO, organ procurement organization; ICU, intensive care unit; UNOS, United Network for Organ Sharing.

the Federal Conditions of Participation of the Centers for Medicare and Medicaid Services, all hospitals are required to contact their local OPO in a timely manner if a patient is expected to expire. The OPO and transplant surgeons, rather than the clinical staff, should assess the suitability of a potential donor. Additionally, the OPO is skilled in approaching the family of potential donors and is well versed in the diagnosis of brain death. The patient's death and the request for donation should remain separate issues. Families may perceive a conflict of interest if these discussions occur in the same setting and several investigators have reported an improved consent rate when there is a temporal separation between notification of brain death and request for donation.(19, 20) Similarly, the primary team should not approach the family about organ donation in order to avoid a perceived conflict of interest. A member of the OPO, uninvolved with the patient's management, should initiate these discussions.(21, 22)

WHO IS A POTENTIAL ORGAN DONOR?
All patients, regardless of age, with a fatal or irreversible disease process should be considered as potential organ donors. The local OPO should be contacted in a timely fashion in order to assess the suitability of potential donation. The patient's history, diagnosis, height/weight, ABO group, hemodynamic data, laboratory values including urinalysis, medications and culture results will assist the OPO in their determination.

Absolute contraindications to donation include: 1) systemic viral infections (e.g., human immunodeficiency, human T-cell leukemia-lymphoma virus, measles, rabies, adenovirus, enterovirus, parvovirus, and herpetic meningoencephalitis), 2) tuberculosis, 3) untreated septicemia, 4) extracranial malignancies (excluding nonmelanoma skin cancers), 5) intravenous drug use, 6) and prion disease.(16)

Infection with hepatitis B or C is not considered an absolute contraindication. Hepatitis-infected organs may be transplanted into similarly infected recipients or into those requiring an immediate life-saving transplantation.(23) Likewise, previous infection with cytomegalovirus (CMV) does not preclude donation. Although efforts to transplant CMV negative recipients with CMV negative organs are encouraged, antiviral prophylaxis has significantly reduced the mortality and morbidity associated with CMV infection.(16)

HOW CAN THE PATIENT BE OPTIMALLY MANAGED FROM A CARDIOVASCULAR PERSPECTIVE?
Physiologic derangements are common after brain death and without support cardiopulmonary arrest generally follows within hours. The cardiovascular effects of brain death are biphasic and are directly related to the progression of neurologic death. Initially, there is an autonomic storm characterized by intense systemic vasoconstriction as the brain attempts to maintain adequate perfusion pressure. With subsequent herniation and loss of brainstem function, the sympathetic overdrive is abruptly terminated resulting in profound hemodynamic instability and frequent dysrhythmias.(24, 25) Anticipating cardiovascular instability can improve organ retrieval and optimize graft outcome. A systematic approach using standardized guidelines and algorithms should aim for normovolemia, a normal blood pressure (mean arterial pressure [MAP] ≥ 60 mmHg), and an optimized cardiac output. Because hypotension is a frequent complication, supporting end organ perfusion in the potential donor requires maintaining a fine balance between volume and vasoactive drugs. Goal-directed therapy using a pulmonary artery (PA) catheter can help navigate this balance and improve organ recovery.(26) Ideally, volume therapy should be adjusted to maintain a wedge pressure of 8–12 mmHg, a CVP of 6–8 mmHg, and a cardiac index above 2.5 L/min/m^2. Packed red blood cells, rather than crystalloid, should be transfused with a goal hematocrit of 30% to in order to maximize oxygen delivery.(27)

Because the excessive use of vasoconstrictive drugs can exacerbate organ hypoperfusion and contribute to myocardial deterioration, vasopressors should only be used if hypotension persists *despite* adequate volume resuscitation. No specific agent, or combination, has been demonstrated clinically to be superior in the management of the potential organ donor. Traditionally, dopamine has been the preferred vasactive agent because of its minimal vasoconstrictive effects on the splanchnic circulation. Recent studies, however, do not support the purported beneficial effect of dopamine on renal or hepatic circulation.(28) Moreover, the vasodilatory shock experienced in brain death may be, in part, the result of a vasopressin deficiency.(29) At low doses, arginine vasopressin (0.01–0.04 U/min), a hormone normally secreted by the posterior pituitary gland, enhances vascular catecholamine sensitivity and decreases the need for additional vasopressor support.(30, 31)

Consequently, the American College of Cardiology recommends using vasopressin as an adjunct in the hemodynamic management of the potential organ donor.(32) Provided the donor is adequately volume resuscitated, high-dose vasopressors are not typically required. Nonetheless, if needed to maintain adequate perfusion pressure, high-dose pressor support does not preclude successful donation.(33)

Although controversial, several animal and human studies have suggested brain death is associated with the development of hormonal deficiencies that contribute to hemodynamic instability. In addition to low circulating levels of vasopressin, deficiencies in cortisol and thyroid hormone may contribute to the hypotension seen in catastrophic brain injury. Supplemental hormonal therapy can augment vasoreactivity and support blood pressure in the potential donor. Corticosteroids enhances vascular reactivity and are associated with a decreased need for vasoconstrictive agents.(16) Similarly, supplemental thyroid hormone may dramatically improve cardiovascular stability. (34) Current cardiovascular recommendations can be found in Table 38.3.

Rhythm disturbances and conduction abnormalities are common especially during and immediately following herniation. Unfortunately, these arrhythmias are highly resistant to standard therapies. With brain herniation, the vagus nerve impulses are lost and therapy with atropine is ineffective. If bradycardia is associated with hypotension, isoproterenol or epinephrine can be used. Ventricular arrhythmias should be treated with lidocaine or amiodarone. Because cardiac arrest in the donor is more common in the setting of hypovolemia, underlying fluid and electrolyte abnormalities should be identified and aggressively treated. Cardiac arrest is not a contraindication to solid organ donation and cardiopulmonary resuscitation and standard advanced cardiac life support (ACLS) protocols should be instituted.(35)

All potential cardiac donors should undergo an electrocardiogram and echocardiogram in order to evaluate cardiac structure and function. Donation, however, should not be excluded on the basis of the initial cardiac evaluation.(36) Cardiac angiography is often performed if the donor is ≥45 years old, requires high inotropic support, or has risk factors for coronary artery disease.(37)

Table 38.3 United Network for Organ Sharing Critical Pathway and Crystal City Recommendations.

Cardiovascular	• Echocardiogram for all potential donors • Pulmonary artery catheter, especially if EF < 45% or on high dose pressors • Hemodynamic goals: MAP ≥ 60 mmHg PCWP ≤ 12 mmHg CVP ≤ 12 mmHg SVR 800–1200 dyne/sec/cm^5 Cardiac index ≥2.5 l/min M^2 Dopamine dose < 10mcg/kg/min Left ventricular stroke work index > 15
Pulmonary	• CXR • Bronchoscopy: define anatomy, rule out infection, pulmonary toilet • Bronchodilator therapy: prevents atelectasis, pulmonary toilet • Pulmonary goals: Maintain tidal volume 10–15 ml/kg FiO2 = 0.40 PEEP 5 cm H$_2$O pO$_2$ ≥ 100 mmHg pCO$_2$ = 30–35 mmHg peak airway pressure <30 mmHg
Electrolyte	• Na ≤ 150 meq/dl • K$^+$ ≥ 4.0 meq/dl • correct acidosis with sodium bicarbonate to maintain pH 7.35–7.45
Endocrine	• Tri-iodothyronine (T3): 4 mcg bolus; 3 mcg/hr continuous infusion • Arginine vasopressin: 1 unit bolus; 0.5–4.0 units/hr infusion titrated to SVR 800–1200 using a PA catheter • Methylprednisolone: 15 mg/kg bolus (repeat q 24 hrs) • Insulin: minimum infusion of 1 unit/hr; titrate to keep glucose 120–180 mg/dl
Hematology	• Use colloid preferentially • PT and PTT ≤ 1.5 X control, transfuse fresh frozen plasma • Hgb > 10.0 mg/dl; transfuse packed red blood cell • keep platelets > 80,000/cm^3 • use <u>albumin</u> for volume resuscitation

Source: Ref(46). And Rosengard BR et al.(42)

WHAT CAN BE DONE TO IMPROVE THE POSSIBILITY OF LUNG PROCUREMENT?

Lung procurement from potential donors remains a challenge. Donation rates are relatively low (≤ 20% of potential donors) and may be secondary to the initial lung injury, respiratory complications, and physiologic changes associated with brain death.(38) The intense vasoconstriction associated with progression to brain death can have a deleterious impact on lung physiology. With profound systemic hypertension, neurogenic pulmonary edema can develop when left atrial pressure exceeds pulmonary artery pressure leading to capillary wall disruption and egress of protein rich fluid into the pulmonary interstitium.(39) Additional iatrogenic injury can occur in the setting of large volume resuscitation and failed lung donation is commonly associated with a markedly positive fluid balance.(40) Using a pulmonary artery catheter to guide fluid administration with a goal pulmonary capillary wedge pressure of 8–12 mmHg is associated with increased lung donation.(41) In the event of over-resuscitation, judicious diuresis may help salvage potentially useable lungs. In order to minimize the risk of pulmonary edema, colloid solutions including the liberal use albumin for volume resuscitation are recommended in potential lung donors.(42)

Attention to "pulmonary toilet" and lung protective ventilator strategies can minimize respiratory complications. Simple measures such as frequent suctioning, bronchoscopy, and the routine use of inhaled albuterol can prevent the accumulation of secretions and the development of atelectasis.(43) Additionally, supplemental high-dose corticosteroids (e.g., methylprednisolone (15 mg/kg)) have been associated with improved lung function and subsequent improved lung donation rates.

(44) Ventilator settings should minimize oxygen toxicity and barotrauma. Optimally, the ventilator settings should achieve a paO2 greater than 100 mmHg using the lowest possible FiO_2 and a pCO_2 between 30 and 35 mmHg. Positive end expiratory pressure of 5–7.5 should be used to promote alveolar recruitment and the end inspiratory plateau pressure should be limited to < 30 cm H_2O. Current recommendations for optimal pulmonary management can be found in Table 38.3.

WHAT ARE THE MOST COMMON FLUID AND ELECTROLYTE ABNORMALITIES?

Hypovolemia and hypernatremia are the most frequent fluid and electrolyte abnormalities encountered in the potential organ donor. Diabetes insipidis (DI) frequently occurs in brain death and is associated with a large free water diuresis. Because patients with severe brain injury frequently receive therapies such as mannitol and diuretics, distinguishing DI from drug-induced polyuria can be challenging. If the urine output is less than 200 cc/h, simple volume replacement should be sufficient. With higher urine output, either low-dose arginine vasopressin or 1-desamino-8-D-arginine vasopressin can be used.

Resuscitation should be geared toward achieving euvolemia and fluid therapy should be guided by central venous pressures or pulmonary artery catheter measurements. Because hydroxyethyl starch can lead to renal tubular epithelial damage and impaired early graft function, it should not be used for volume expansion. (45) According to UNOS recommendations, colloids (e.g., albumin) rather than crystalloids should be used for resuscitation in order to prevent pulmonary edema.(46)

Once euvolmia has been achieved, hypotonic solutions such as lactated Ringer's solution or half-normal saline should be used to normalize serum sodium (Na ≤ 150 meq/dL).(46) Persistent hypernatremia in the potential donor has been linked with graft loss after liver transplantion and elevated serum sodium should be rapidly corrected.(47)

Significant fluid shifts in the potential donor can also result in other electrolyte abnormalities (e.g., hypokalemia, hypomagnesiumemia, and hypophosphatemia). Serum electrolytes should be monitored frequently (e.g., every 2–6 h) to guide electrolyte and fluid replacement. Potassium should be replaced to ≥4.0 meq/dL and acidosis should be corrected to a goal pH of 7.35–7.45. If necessary, sodium bicarbonate can be added sterile water or half-normal saline to normalize the acid–base status.(16)

WHAT IS THE ROLE OF HORMONE REPLACEMENT OR SUPPLEMENTATION IN THE POTENTIAL ORGAN DONOR?

Brain death frequently results in hypothalamic–pituitary dysfunction, but the degree of hormonal insufficiency is variable. A vasopressin deficiency is the most common endocrine disorder and without treatment DI may lead to profound volume and electrolyte disturbances. Because the anterior pituitary has a different blood supply from the posterior pituitary, some pituitary function may be preserved even with brain herniation. If the anterior pituitary is affected, thyroid indices and cortisol levels may also be suppressed.

Routine hormonal supplementation remains controversial. While some experts recommend only using hormonal therapy in hemodynamically unstable donors, others suggest a broader application in order to maximize graft procurement and function. The UNOS Critical Pathway for the organ donor recommends treating all potential donors with a methylprednisolone bolus (15 mg/kg q 24 h), triiodothyronine (T_3) (4 μg bolus, then 3 μg/h infusion), arginine vasopressin (1 unit bolus, then 0.5–4 units/h infusion titrated to a systemic vascular resistance of 800–1,200 dynes/sec/cm) and insulin (infusion 1 unit/h minimum, titrate to blood glucose 120–180 mg/dL). In a retrospective analysis of 10,292 brain-dead donors, adherence to the UNOS hormonal replacement protocol resulted in a 22.5% increase in the number of organs transplanted per donor.(48) Moreover, both corticosteroid and T_3/T_4 therapy have been shown to independently decrease the risk of recipient death within 30 days and substantially decrease the risk of early cardiac graft dysfunction.(49)

The primary disadvantage associated with the routine use of hormonal replacement is cost. Rosendale et al. estimate an increase of $3,000–$4,000 per donor with strict implementation of the UNOS hormonal replacement recommendations. Placement of a pulmonary artery catheter ($500–$1,000) and the infusion T_3 ($1,500–$1,750) constitute the major expense. (48) Intravenous T_4 is significantly less expensive, but requires peripheral conversion to the active T3. In high catecholamine states, there is a preferential conversion of T4 to the inactive rT3 rather than the active T3.(50) Given these concerns, the Cardiac Consensus Conference Report and UNOS recommend using intravenous T_3.(51, 46) When T_3 is not available, T_4 may be substituted with the caveat that the conversion to active T_3 may be capricious and the hemodynamic benefit may be delayed.(48)

ARE THERE ANY HEMATOLOGIC CONCERNS?

Patients with severe traumatic brain frequently develop coagulation abnormalities with over 50% developing a coagulopathy and/or thrombocytopenia.(52) The coagulopathy experienced in severely brain injured patients is multi-factorial. In addition to factors such as hypothermia, acidosis, and dilution, severe brain injury results in the release of thromboplastin, cerebral gangliosides, and plamsminogen-rich substrates into the systemic circulation. These substances stimulate the development of disseminated intravascular coagulopathy.(53) Liberal blood product administration should be used to treat anemia (hematocrit > 30%) and correct coagulopathy (prothrombin international normalized ratio < 1.5, platelet count >80,000/cm³).(16) Only cytomegalovirus-seronegative blood products should be used and all blood should be leukocyte filtered in order to decrease the risk of sensitization. In order to decrease the risk of hypothermia, blood products should be warmed on infusion.

> Over the next 48 h the patient does not progress to brain death. His prognosis for a meaningful neurologic recovery remains grim. His family expresses an interest in still pursuing organ donation.

Table 38.4 The University of Wisconsin Donation after Cardiac Death criteria for predicting asystole following the withdrawal of life support.

Criteria	Assigned Points
Spontaneous respirations after 10 minutes	
Rate >12	1
Rate <12	3
TV >200 cc	1
TV <200 cc	3
NIF > 20	1
NIF < 20	3
No spontaneous respirations	9
Body mass index	
<25	1
25–29	2
>30	3
Vasopressors	
No vasopressors	1
Single vasopressor	2
Muliple vasopressors	3
Patient age	
0–30 yrs	1
31–50 yrs	2
51+ yrs	3
Intubation	
Endotracheal tub	3
Tracheostomy	1
Oxygenation after 10 minutes	
O_2 saturation >90%	1
O_2 saturation 80–89%	2
O_2 saturation <79%	3

Scoring:
8–12: High risk for continuing to breath after extubation
13–18: Moderate risk for continuing to breath after extubation
19–24: Low risk for continuing to breath after extubation

TV, tidal volume; NIF, negative inspiratory force.
Source: Bernat JL et al.(59)

IS IT POSSIBLE TO PURSUE ORGAN DONATION WITHOUT FORMALLY DECLARING BRAIN DEATH?

Donation after cardiac death (DCD), previously known as non-heart-beating donation, provides the opportunity of organ donation to patients with an imminently terminal illness. In this setting, life-sustaining therapy is withdrawn and death is determined using cardiopulmonary criteria. Prior to the adoption of brain-death criteria in the 1980s, all organs were recovered from DCD donors.(54) Warm ischemia time, however, limited the opportunity for multi-organ donation. With the implementation of donation following brain death, warm ischemia times were minimized and the success rates for multi-organ donation dramatically improved. Currently, DCD provides only a small percentage of available organs for donation.

With the increasing disparity between the number of organs needed and the actual number donated, DCD is being re-explored. Widespread implementation of DCD protocols could potentially increase the donor pool by 20–25%.(55) Moreover, advancements in DCD protocols have led to success rates in lung, liver, pancreas, and kidney transplantation that parallel those of brain-dead donation.(56–58)

In order to minimize warm ischemia, DCD is best performed in the operating room. According to a 2005 national consensus conference on DCD, at least 2 minutes of observation following the cessation of cardiopulmonary function is required before organ recovery procedures can commence. The pre-recovery administration of pharmacologic agents remains controversial. Although the administration of intravenous heparin at the time of withdrawal of care is considered standard of care, the use other medications (e.g., phentolamine, steroids, mannitol) vary from institution to institution and require informed consent of the family. Similarly, some protocols recommend premortem vascular cannulation in order to facilitate rapid infusion of preservation fluids post-mortem. Any premortem procedure or intervention done for the purpose of DCD absolutely requires informed consent of the patient or the patient's family.(59)

Table 38.5 UNOS criteria for identifying potential DCD patients.

Respiratory Rate	Assist Device	Pulmonary Support	Vasopressors
Apnea	LVAD	PEEP ≥ 10 and	Norepinephrine,
RR <8	RVAD	SaO2 ≤ 92%	epinephrine, or
RR >30 during trail off	V-A ECMO	Fi02 ≥ 0.5 and	phenylephrine
mechanical ventilation	Pacemaker with	SaO2 ≤ 92%	≥ 0.2 mcg/kg/min
	unassisted rhythm of <30	V-V ECMO	Dopamine
	IABP 1:1 OR dobutamine or dopamine		≥ 15 mcg/kg/min
	≥ 10 mcg/kg/min and		
	CI ≤ 2.2 L/min/m^2		

RR, respiratory rate; LVAD, left ventricular assist device; RVAD, right ventricular assist device; V-A ECMO, venoarterial extracorporeal membrane oxygenation; PEEP, positive end-expiratory pressure; SaO2, arterial oxygen saturation; FiO2, fraction of inspired oxygen; V-V ECMO, venovenous extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; CI, cardiac index.
Source: Bernat JL et al.(59)

HOW CAN ONE PREDICT IF A PATIENT WILL BE A SUCCESSFUL DCD DONOR?

Because the limiting factor is warm ischemia time, the success of DCD depends on accurately predicting when a patient will expire after the withdrawal of support. The University of Wisconsin Donation After Cardiac Death Evaluation Tool was developed to predict the likelihood that patients with severe neurologic injury would expire within 120 minutes. Using a scoring system (8–24 points) that evaluates eight dimensions, the UWDCD tool assess the patient's ability to breath without the assistance of the ventilator, their cardiovascular stability, their age, and their body mass index (see Table 38.4). In a prospective study of 43 potential DCD donors, the UWDCD tool predicted cardiac death within 60 minutes 83.7% of the time and within 120 minutes 74.4% of the time.(60)

A UNOS DCD consensus committee has also developed a set of criteria that can assist in identifying potential DCD candidates (see Table 38.5). In a prospective, observational cohort study of 505 patients, the likelihood of expiring within 60 minutes increased with the number of identified UNOS DCD criteria. For example, 52% of patients with 1 criterion expired within 60 minutes, whereas 82% of patients with three criteria died within an hour of withdrawal of life-support. Regardless of which assessment tool is chosen, identifying which patients are likely (or unlikely) to die rapidly enables the team caring for the potential DCD candidate to plan appropriately and can enhance the psychosocial support of both the staff and the family.

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39 End of life care in the ICU: Ethical considerations a family-centered, multidisciplinary approach

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An active 82 year-old man with a history of chronic obstructive pulmonary disease, Coronary artery disease (requiring angioplasty with stents 4 years ago), hypertension, gout, and diverticulitis presents with sudden onset of severe abdominal pain and distention. He reports that he had been having mild left lower quadrant pain with chills for the past 5 days and the pain had become significantly worse. Upon work-up, he is found to have perforated diverticulitis and is taken to the operating room. Severe diverticulitis of the sigmoid colon is found with perforation and peritoneal contamination. The involved sigmoid colon is resected and the proximal end is brought out as an end-colostomy (Hartman's procedure). During the operation, his blood pressure is labile and requires high volume resuscitation. Post-operatively, he is unable to be extubated and is admitted to the ICU. Over the next 2 weeks, his post-operative course is complicated by development of several intra-abdominal abscesses and abdominal compartment syndrome necessitating decompressive laparotomy and abscess drainage. He also develops ventilator-associated pneumonia and the ICU team is unable to wean him off the ventilator. He has been fed enterally through a naso-jejunal feeding tube and the ostomy is now functional. His white blood cell (WBC) count is 23 k, Hct is 28%, and his BUN and creatinine are 47 and 2.1, respectively, though he still maintains a urine output of >30 cc/kg/h. At this point, his physicians think that he still has a reasonable chance of recovery and recommend tracheostomy placement and a percutaneous feeding tube. However, his grandchildren (his only remaining relatives) are unsure about this course of action, and question whether he would want to "live on a ventilator" if continued treatment is "futile". The patient is unable to communicate his wishes. His nursing staff notes that he is confused and intermittently agitated, but does not appear to be uncomfortable with analgesics and sedation.

With the advent of technology and the advancement of medical care, our ability to treat and support the critically ill has opened up a host of ethical and moral challenges. Differences in viewpoints between patient, family, and medical staff result in conflicts that further add to the complexity of modern ICU management. Recent efforts to improve the quality of care in the intensive care unit has turned the focus to family satisfaction and providing family-centered care as part of patient-centered care. (1) Often critically ill patients in the ICU are unable to make their own decisions (2) and the role of the family becomes essential. Indeed, most patients want their families to be part of the decision-making process,(3–5) regardless of whether they agree or disagree.

As efforts become futile, care must be balanced with comfort, for both patients and families. Such care comes as a cooperative effort of multiple specialties such as physicians, nursing, rehabilitation services, social work, psychiatry, care management, religious services, and ethics committees. The evolving role of the intensivist will be to integrate these services and facilitate communication. In addition to mastering the intricacies of modern medical management, the new intensive care practitioner will need to be skilled in the art of diplomacy, negotiation, counseling, and coordination of these diverse resources.

"FUTILE CARE" AND PREDICTION OF OUTCOMES

The concept of "futile care" has been the subject of intense debate. Initial attempts to define futility have been value laden and fail to integrate physiological definitions with societal and personal assumptions such as quality of life, religion, and personal belief systems. Several papers in the last two decades attempted to define futility using quantitative or physiological variables,(6, 7) differentiating this view of futility from that based on the personal beliefs and ethical frameworks of the patient. "Qualitative" futility may be seen that goes beyond the wishes of the patient according to his or her goals. A recent survey of health-care providers defined "medical futility" as "the use of considerable resources without a reasonable hope that the patient would recover to a state of relative independence or be interactive with his or her environment."(8)

Designating a case as futile should, in theory, transform the dynamics of the decision-making process because treatment decisions cannot, by definition, alter the outcome. Although agreement is not universal, many physicians maintain that physicians are under no obligation to provide futile care.(9, 10) Unfortunately, it is unclear whether physicians can consistently and accurately identify futility in all but the most obvious circumstances.(11) Moreover, progress in medical treatment has made it clear that some situations previously deemed futile may not be, raising the possibility that, under certain circumstances, futility may be no more than a self-fulfilling prophecy.(12) More recent debates have shifted away from the definition of futility and focused on developing mechanisms to resolve conflicts regarding treatment goals and improving communications with patients and families.(13)

Several studies have shown that physicians' clinical judgment regarding functional outcomes and survival is fairly accurate.(14) Combining clinical judgment with objective scoring systems, such as Acute Physiology and Chronic Health Evaluation scoring and evolving organ dysfunction scales (15), allow for reasonably accurate prognostication when discussing outcomes with patients and families. However, physicians find discussions of prognostication challenging and may avoid doing so for fear of being wrong.(16) In a study by White et al. audiotaped physician-family conferences were reviewed and found that while discussions of functional status and quality of life were commonly discussed (86% of taped conferences), discussion regarding survival were far less common (63% of conferences).(17) Education

was also significantly linked to provision of prognostic information. Families with lower levels of education received less prognostic information than those with higher educations. Therefore, many families find themselves confused or poorly informed regarding predicted outcomes, hindering their ability to make fully informed patient care decisions, and exacerbating physician-family conflicts.

> After discussion with the critical care team, the family requests that the patient receive no "extraordinary measures," but wishes to continue tube feedings, antibiotics, analgesic, and sedative medications. The staff feels that this is contradictory and that the patient should be made comfort care only.

QUALITY CARE AT THE END OF LIFE

"Quality care" is defined by the Institute of Medicine as safe, timely, efficient, effective, equitable, and patient centered.(18) However, defining the scope of care is dependent on the values and priorities of patients and families. Few interventions completely fulfill these criteria and a balance must be found for each individual patient. (For example, optimizing pain and sedation medication dosing in order to maximize comfort and minimize respiratory depression, or performing surgery with its greater risk of associated complications.) Recognizing that the aggressiveness of care lies along a continuum and is value based, efforts to differentiate care as "extraordinary" versus "routine" have failed. Attempts to make this distinction in the clinical setting may be obsolete and is rarely useful. The essential component is elucidating the intent of the scope of care, and clearly defining the goals of therapy. Often this is an ongoing process as goals and prognoses change, and require a commitment to serial, directed discussions.

Daily multidisciplinary rounds help clarify the goals and daily therapeutic plans. In our institution, some of us have found incorporating family into "work rounds" allows for improved family understanding of the patient's condition and care plans. Family presence also allows for improved dialogue regarding goals of therapy and expression of families' questions and concerns.

Regardless of the goals of therapy, palliation and the relief of suffering should always be integral to the care of the ICU patient. It is a common misconception that the goals of palliative and life-saving care are mutually exclusive. Throughout the course of therapy, palliation is provided concomitant with curative and life-extending therapies, until such therapies become ineffective and palliation becomes the primary goal of care.(19, 20) Pain management is a key area of research and quality improvement in health care. In the ICU, the use of pain scales allows titration of analgesics to an appropriate level of comfort without over-sedation. Use of behavioral pain scales may improve our ability to assess for comfort in the ICU patient that is unable to communicate.(21)

> While the patient's wife is his power of attorney, they had never discussed his wishes in these circumstances and she is unsure what to do. The children and grandchildren, with whom the patient is very close, have differing views of what he would have wanted.

DECISION MAKING IN THE ICU

The right of a patient to determine what is in his or her own best interest is one of the fundamental principles in medicine. While a patient may hold views contrary to those of his or her family or caregivers, he or she is the final arbiter of what care can or cannot be given, so long as a patient's decision does not compromise the ethical views of the practitioners. Caregivers must be mindful not to impose their values and beliefs on patients, respecting their right to autonomy and self-determination. In that way, the primary role of the health-care team is to provide information, mediate dialogue, and to guide the decision-making process. Similarly, the health-care team must help patients communicate their wishes, help families and caregivers speak on the behalf of their loved ones who are unable to express their wishes, and enact those wishes in an ethically, socially, and psychologically acceptable manner. Finally, the healthcare team plays a key role assisting families and loved ones in their grieving process.

In order to make decisions for themselves, patients must have the *capacity* to make decisions for themselves. A patient's capacity is defined as an understanding of their medical condition, treatment options, risks and benefits of interventions, prognosis, and the ability to communicate those wishes and give informed consent. Informed consent consists of the legal obligation of the physicians to provide accurate and sufficient information, including discussion of risks and benefits, in order for patients (or their proxies) to make intelligent decisions regarding medical care.(22) While documentation of the consent itself is a medico-legal requirement, it is the process in obtaining informed consent that is important. Informed refusal is the counterpart to informed consent. Care providers have the obligation to ensure that decisions to refuse care are also made by the same ethical standards; that risks and benefits, alternative options and prognoses are understood, and that the patient has the capacity to make that decision.

When patients lack the capacity to make their own decisions, designated proxies and family members serve as representatives of the patient.(23) Where a designated proxy is not assigned, next of kin assume responsibility. In adults, proxies serve as "substituted judgment" in which they represent the wishes of the patient as if they were capable of expressing their views. In minors, parents and guardians make decisions based on the best interests of the patient. An exception, however, is made for "mature minors." Based on a 1967 court case (Smith v. Seibly, 72 2n.2d 16.), some youth may be treated as adults by health-care providers, based on an assessment and documentation of his or her maturity. State laws differ on the status of common law marriage and civil unions, and where disagreement exists, the court system is sometimes utilized.

As the focus in critical care shifts toward a greater sensitivity towards patient and family satisfaction in the ICU, the family has become increasingly involved even when patients have the capacity for medical decision making. Indeed, as previously noted, even when patients and families disagree, patients prefer to have the involvement of the family in the discussion. While they may not override the wishes of the patient, families (and increasingly, extended family, friends, companions, clergy, etc.) have played a greater role as consultants and support to the patient. This is particularly true for members of certain ethnic groups, which may be more inclined culturally to assign family members a predominant if not dominant role in the decision making

process.(24, 25) Mediating these discussions and negotiation of care plans and conflicts with patients and families has become part of the intensivist's role.

Many ICU family members experience symptoms of anxiety and depression, which could impair their ability to participate in decision making.(26) To aid in these discussions, the armamentarium has expanded and associated staff such as nursing, social workers, psychiatrists/ psychologists, clergy, case managers, attorneys, and ethicists may be helpful in sorting out complex issues surrounding medical decisions. Several studies have shown that most families prefer a process of shared decision making, which includes active input from members of the medical team, rather than relegating responsibility to the family alone.(27)

The multidisciplinary family meeting has become an essential part of these discussions in the modern ICU. Key components include but are not limited to 1) resolving conflicts among members of the treating time before the meeting, 2) determining the family's level of understanding and providing the opportunity to describe the patient's history and preferences if known, 3) sharing necessary medical information with the family, including the prognosis, 4) discussing treatment options, and 5) agreeing upon a plan for care as well as plans for follow up.(28) Statements of support for the family's choices are essential in addition to providing assurance that the patient will not be abandoned if the choice is to limit the focus to comfort measures only. In addition to formal family meetings, other methods of increasing family involvement and improving communication include regular, scheduled discussions with family, inclusion of family on ICU rounds, and involvement of family in resuscitation and procedures.

With the increasing complexity of communications between caregivers, patients, and families, conflicts become inevitable and modern negotiation techniques have been increasingly adopted to manage these discussions. The most popular of these is the "principled negotiation" approach, which holds to four basic tenets; separate the problem from the people, focus on interests, not positions, generate options before reaching a decision, and reaching an agreement based on objective criteria.(29) Taking such an approach, combined with improved lines of communication, may minimize the number or intensity of conflicts and defuse the intense emotional trauma of such discussions.

ADVANCE DIRECTIVES

Patient Self-Determination Act passed in November of 1990 requires that all Medicare and Medicaid providers give adult patients information regarding advance directives, including the right to participate and direct their own health-care decisions, the right to accept or refuse medical interventions, the right to create an advance directive and the right to be informed about a program or institutions policy regarding such rights.(30)

Encouraged as a means to empower the patient, these advance directives are comprised of three elements; a living will, designation of a health care proxy, and specific medical orders such as do-not-resuscitate (DNR) and do-not-intubate (DNI). The living will serves as a means of delineating the extent of medical treatment desired based on the patient's goals of therapy.

Unfortunately, living wills have multiple shortcomings. While a living will can imply what a patient would want done in certain situations, no document can fully cover all possible contingencies. In particular, most living wills address treatment preferences limited to narrow circumstances, such as terminal conditions and states of permanent unconsciousness, making them irrelevant when these conditions do not apply. Moreover, many patients and family members do not understand or consistently agree with the purpose and implications of their own living wills, thus raising doubt about how accurately they reflect treatment preferences. (31) Therefore living wills are evolutionary and negotiable and are subject to interpretation by family and caregivers. A health-care proxy is more substantial in that a specific person is designated to represent the wishes of the patient in the event of incapacity. The designated person may change over time or according to the occasion, but for that period, that person has the legal power to direct care. Orders such as DNR/DNI are more specific, but again may be revoked in certain situations (acute, reversible processes such as need for surgery or treatment for pneumonia) or subject to interpretation.

The majority of people still does not have designated health-care proxies or advanced directives, leaving decision making responsibility to family members who may not know or feel confident about patients' specific preferences.(21, 32) For these reasons, when patients present to the hospital, open discussion regarding advance directives and identification of proxies should be initiated for when the need arises.

> After extensive discussions, members of the family still disagree about what the patient would have wanted done, and the staff also disagree regarding the appropriateness of aggressive care. One of the nursing stuff approaches the family and recommends an Ethics Committee consult to help "sort through the issues."

ETHICS COMMITTEES AND ETHICS CONSULTS

Ethics committees were created as a resource to practitioners, patients, and families as a response to the increasingly common and complex ethical issues that arise during the care of hospitalized patients. Presently, over 80% of hospitals nationwide have standing ethics committees as part of their institution. These serve to provide guidance and education in ethical matters both in the clinical setting (through case consultation), and as a resource to the hospital and health-care organization through policy recommendation and teaching.(33)

The Joint Commission (formerly known as the Joint Commission for the Accreditation of Healthcare Organizations) requires that hospitals have mechanisms in place to address ethical issues, including mandates to have organizational codes of ethics and set mechanisms to protect patients' rights to confidentiality, privacy, appropriate communication, advance directives, and end-of-life care. Ethic committees, though not standardized in their mechanisms or models, serve to meet many of these requirements.

Different models of ethics committees exist, but they share the same multidisciplinary approach and may include physicians,

nurses, social workers, clergy, attorneys, administration, and academic ethicists. Diverse viewpoints of the ethics team aid in negotiation and clarification of the goals of care and conflict resolution.

Case consultation remains the most common function of ethics committees, but approaches also difference from institution to institution. Full committee involvement may not be required, feasible or desires and in a number of institutions, "ethics consultations" comprised of individuals, smaller teams or sub-committees address case consultation requests and have had some success. (34) After consultation, the findings of the committee may be in the form of suggestions or recommendations, or may be more substantial, including medical or legal intervention. In the overwhelming majority of states, hospital ethics committees do not have legal power, but are the local authority on ethical matters. The model of ethics committees adopted by individual institutions will depend on the needs and resources unique to each institution.

TRIAGE

With growing frequency, intensivists will be expected to choose between patients competing for a limited number of ICU beds. The need to triage beds is likely to become more common with growing numbers of elderly, chronically ill patients and worsening manpower shortages.(35) Threats of bioterrorism and the possibility of influenza pandemics mandate that each institution develop ethically sound triage protocols before the need is urgent.(36)

Under triage, the focus shifts from individual treatment choices to considering approaches most likely to benefit the population seeking care. Some patients may need to be denied ICU care in favor of others demonstrating a more compelling need.(37) To minimize the need to triage, steps should be taken to optimize bed availability, for example, by expediting discharges and transfers; ensuring high quality care outside the unit (for example, in step-down and telemetry units); and following practices shown to decrease ICU length of stay, including addressing end-of-life goals and promoting palliative care options.(38)

An objective scoring system is essential to effective, ethically sound triage. Pertinent factors include severity of illness, how likely a patient is to benefit from ICU care, and considering whether a patient can be managed safely outside the ICU.(36) Top priority should be reserved for patients sick enough to require the ICU (for example, patients with septic shock and respiratory failure) but not too sick to benefit. Lower priority should be assigned to patients who can be managed safely and effectively outside the unit and to those expected to fare poorly even with ICU care. Decision making responsibility should be restricted to intensivists with the expertise and experience necessary to implement institutional guidelines appropriately. For patients triaged out of the ICU, all efforts must be made to optimize care, recognizing the limited resources available. Palliative care should be offered as circumstances dictate. Finally, successful triage requires support from hospital administrators, attorneys, and local experts in bioethics.

SUPPORT RESOURCES

Even though families with patients that had poor outcomes report higher rates of satisfaction (due to increased communication) (39),

support of families have historically been poor. Families undergo significant stress and anxiety during this period (40) and meeting the spiritual needs of families is an important component of end of life care.(41) Families report higher rates of care satisfaction if a pastor or spiritual advisor was involved in the last 24 h of care of their loved ones.(42)

The team approach to should include members trained in physical, social, psychological, spiritual, and legal aspects of health care.(43) Different models of these support systems exist, including palliative care consultation teams, bereavement services, hospice programs, and dedicated inpatient units. In addition to provision of support to patients and families, support for staff is also needed for continued education and training, as well as for emotional counseling and support.

Regardless of which model is utilized, regular and systematic evaluation is an important part to quality improvement. Routine quality review and case review ensure that quality standards are met and identify areas of education and improvement.

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40 Acute trauma-related coagulopathy
Bryan A Cotton and John B Holcomb

A 20-year-old male arrives in the Emergency Department in extremis after sustaining a single gunshot wound to the right upper quadrant. The patient arrives with a patent airway but is hypotensive and tachycardic. He has a carotid pulse. The patient has received approximately 500 mL of crystalloid through a singe large bore (14 G) peripheral IV placed en route. A quick neurological examination reveals he moves all four extremities but his Glasgow Coma Scale is 9. The patient's airway is secured with rapid sequence intubation and two units of packed-red blood cells are "spiked and hung." A chest radiograph (CXR) is obtained and a focused assessment for the sonography of trauma (FAST) is performed. The CXR is negative for injury, while the FAST demonstrates fluid in all three abdominal windows. The patient is immediately transported to the operating room and a type and screen sent to the blood bank.

The majority of deaths from trauma occur in the first few hours following injury, with hemorrhage accounting for the largest percentage of deaths within the first hour of arrival at a trauma center. Hemorrhagic shock and exsanguination account for over 80% of deaths in the operating room and nearly 50% of deaths in the first 24 h following injury.(1–3) Addressing exsanguinating hemorrhage early and in an aggressive fashion is critical to patient survival.

Traditionally, the development of acute trauma related coagulopathy was felt to be an intra-operative or early ICU phenomenon. However, a growing body of evidence has demonstrated that coagulopathy and thrombocytopenia are frequently present on admission in severely injured patients, and the degree of coagulopathy has been correlated with outcome.(4–6) Niles and colleagues have recently examined the prevalence of acute traumatic coagulopathy in the military setting and noted that almost 40% arrive coagulopathic.(7) In the civilian setting, Brohi and colleagues evaluated the coagulation parameters of 1,088 patients immediately upon arrival to the emergency department.(4) The authors found that almost 25% of patients arrived coagulopathic, and was associated with shock, modulated via the protein C pathway.(8) However, among those patients who receive a massive transfusion (> 10 units blood in the first 24 h), Cotton et al. noted that 70% of these patients will have elevated PT on arrival and 49% will have a platelet count less than 100,000.(9) Finally, while massive transfusion is rare (2–3%) among all admitted trauma patients, they have a 59% mortality and represent the group with a large potentially preventable component.(10)

WHAT IS THE ROLE FOR A MASSIVE TRANSFUSION PROTOCOL IN THIS PATIENT?
Without significant prior coordination between multiple departments, once you have thought about treating coagulopathy or act on abnormal lab values, it is likely too late to impact survival in such a patient. In the absence of a pre-defined exsanguination protocol, access to appropriate blood components and sufficient quantities of the same may be significantly delayed. As many severely injured trauma patients arrive at the hospital with coagulopathy already present, any delay in the prompt replacement of blood products may result in an exacerbation of the coagulopathy with ongoing consequent hemorrhage and, ultimately, higher mortality. Military physicians have reported that the application of *damage control resuscitation* has resulted in a significant reduction in combat-related mortalities in both Iraq and Afghanistan. (11) This process involves the early delivery of blood component therapy (packed red blood cells (PRBC), plasma, and platelets), permissive hypotension, and minimizing crystalloid-based resuscitation. Borgman et al. noted an 8-fold reduction in mortality by increasing the use of plasma in massively transfused combat injured patients.(12) Cotton and colleagues then implemented a protocol to address exsanguinating hemorrhage in the most severely injured patients.(9) This protocol delivered red-blood cells, plasma, and platelets in an aggressive and pre-defined manner. The authors found a 74% reduction in the odds of mortality. Finally, Holcomb et al. have recently published the results of a retrospective, multicenter study of massive transfusion in 16 Level 1 trauma centers. They found that increased plasma and platelets were associated with improved 24 h and 30-d survival, without an increase in multiple organ failure (MOF) as a cause of death.(10)

WHAT ARE ITS COMPONENTS AND/OR RATIOS?
In the early post-operative phase, crystalloid-based strategies should be approached with caution and the implementation of more aggressive and proactive blood-product regimens should be considered. Currently, there are no prospective randomized trials to suggest how much and how fast these products should be given. Unfortunately, all the data in this field is retrospective. However, there are several large retrospective studies that would suggest administering packed-red blood cells and thawed plasma in a 3:2 and possibly even a 1:1 ratio while coagulopathy is being actively addressed. A protocol advocated by Holcomb and colleagues involves the administration of one unit of thawed plasma and one pack of platelets with each unit of PRBC transfused.(10)

The protocol studied by Cotton and colleagues involves the use of two units of plasma per three units of PRBC and one single donor pheresis pack of platelets for every five units of PRBC. (9) Similarly, Duchesne et al. have questioned the last 60 years of resuscitation practices, based on their improved results with increased plasma-based resuscitation.(13) The preponderance of data in this evolving field suggest that increased plasma and platelet use, accompanied by decreased crystalloid use, improves outcome.

The patient undergoes damage control laparotomy and packing for a Grade IV liver laceration with 5 L of blood loss. He is transferred to the surgical/trauma ICU with a temperature of 33°C, a systolic blood pressure of 110 mmHg, pH of 7.2, and a low ionized calcium. His fibrinogen is low (90), international normalized ratio (INR) elevated at 2.0, and platelet count decreased at 90, 000/mm^3.

Reversing coagulopathy, acidosis, and hypothermia during hemorrhagic shock resuscitation represents the foundation of damage control principles. Of the three, coagulopathy is most affected by the presence and severity of the other two.(14) The incidence of coagulopathy has been shown to increase with concomitant head injury and worsening injury severity scores, with over 40% of patients with ISS of 30 or greater having documented coagulopathy. The causes of resuscitation-related coagulopathy are complex and multifactorial, including, consumption, acidosis, genetic, comorbidities, medication, hemodilution, hypothermia, and other metabolic derangements.(15)

Prevention of the early coagulopathy of trauma (or attenuating its severity) centers on limiting ongoing tissue injuries and hypoxia, and preemptive transfusion of clotting factors and platelets. Dilutional coagulopathy is a potentially preventable recognized complication of over zealous crystalloid administration and is treated by using plasma as a primary resuscitation fluid, transfusing platelets to keep the counts > 100,000 and minimization of crystalloid-based strategies.(16) In healthy patients, hypothermia impairs platelet aggregation at 34°C and disturbs the function of clotting factors at 32–33°C. However, in injured patients arriving from the operating room following resuscitation with clotting factor deficient crystalloid and packed-red blood cells, disturbances in coagulation may be observed as early as 35°C. (17, 18) Rapid rewarming has been shown to improve survival in hypothermic trauma patients.(18) Given this, it may be warranted to address the contributing factors of coagulopathy more aggressively in an effort to minimize their additive effects until normothermia is restored.(19)

WHAT IS THE ROLE FOR ACTIVE REWARMING?

Hypothermia (<35°C) can significantly impact the outcome of the severely injured patient. Hypothermia leads to decreased oxygen consumption and an increase in anaerobic metabolism (and acid by-products), impaired cardiac performance, and lethal arrhythmias. While 28°C is usually held as the definition of severe hypothermia (and carries a 10% mortality in accidental hypothermia), in trauma patients, similar degrees of hypothermia result in devastating consequences with an almost 100% mortality.(20, 21) In light of this, a separate classification is reserved for trauma patients and is defined as: mild hypothermia (34–36°C), moderate hypothermia (32–34°C), and severe hypothermia (< 32°C). (17) Cold fluids and blood products infused into these patients can dramatically lower the core body temperature. Additionally, exposure, open cavities, and immobilization lead to significant conductive, convective and evaporative losses.

In injured patients arriving from the operating room following resuscitation with clotting factor deficient crystalloid and packed-red blood cells, disturbances in coagulation may be observed as early as 35°C.(18, 22) Given this, it may be warranted to address the contributing factors of hypothermia and coagulopathy more aggressively in an effort to minimize their additive effects until normothermia is restored. Additionally, the efficiency and overall activity of most clotting factors are substantially reduced in an acidic environment (< 7.40).

Several methods exist to address heat loss (and reversal of hypothermia) from a conductive standpoint. Initially, and with less severe hypothermia, wrapping the patient with warmed blankets may be adequate. Care should be taken to cover the distal extremities and the entire scalp. As well, forced-air warming systems conduct heat directly to the skin and do so quite efficiently.(23–26) Whenever possible, warmed fluids should also be used in these patients and the ventilator circuit should be adjusted to provide warming of inhaled air. The inspired gas should be heated to 41°C and the ventilator fully saturated to increase heat conductance to lung vascular beds. The rate of rewarming through such methods ranges from 1 to 2°C per hour. To maintain current temperature, hot water bottles, heating pads, and radiant sources of heat can be used.

Various forms of active core rewarming exist and are much more efficient, though more invasive, than those previously listed. Peritoneal dialysis provides heat in the form of conductance through direct action on intraperitoneal structures and indirectly through the hemidiaphragms to the heart and lungs. (22, 27) This is usually performed through a catheter which delivers heated dialysate at 40–45°C into the peritoneal cavity. Initially, 2–3 L are infused and left for approximately 30 minutes. The rate of rewarming through peritoneal dialysis ranges from 2 to 3°C h. Pleural lavage with 40–45°C fluid raises core temperature approximately 2–3°C per hour. However, both this and the peritoneal dialysis are quite labor intensive, invasive, and requires large-volume flow rates.

Once the physician has determined the need for invasive maneuvers, an active rewarming method using extracorporeal techniques should be employed. While cardiopulmonary bypass represents the "gold standard" in active core rewarming of severely hypothermic patients (increasing core temperature by 1–2°C every 5 minutes), it is incredibly labor intensive, requires significant set up time, and need for cut-downs for access.(22) As well, it requires systemic heparinization which is often contraindicated in this patient population. Alternatives to bypass are continuous arteriovenous rewarming and continuous venovenous rewarming techniques. These techniques use closed circuit flow of the patient's own blood through a warming device, warming the core temperature at a rate of 3–5°C per hour. Both techniques are less labor intensive than bypass, do not require the level of skilled personnel, and are much quicker to set up. The ability to utilize percutaneous access as well as perform rewarming without systemic heparinization is also a benefit in the damage control population.

WHAT IS THE ROLE FOR RECOMBINANT FACTOR VIIA ADMINISTRATION?

Recombinant factor VIIa (rFVIIa) has been evaluated and advocated as an adjuvant for treatment of coagulopathy in patients such

as this example with severe torso hemorrhage. rFVIIa binds to tissue factor at the site of endothelial injury, triggering a local coagulation process that stops bleeding.(28) Many retrospective studies have suggested that the use of rFVIIa reduces the incidence and severity of coagulopathy in severely injured patients with ongoing transfusion requirements.(28–30) Several studies from the ongoing war in Iraq associate improved patient outcomes with use of rFVIIa.(31, 32) Finally, Boffard recently published a phase II study of rFVIIa use in trauma patients, demonstrating a reduction in RBC use and a trend toward less MOF.(33) Despite these findings and its growing acceptance as an adjunct in severe hemorrhage, there has been no prospective randomized evidence demonstrating reduction in mortality with its application in the trauma population. However, the occasional impressive achievement of hemostasis and potential for improved individual patient survival have resulted in its continued use in severely injured patients. Up to 20% of massively transfused trauma patients receive rFVIIa.(10) However, one should understand that when using this agent in the setting of massive transfusion and likely coagulopathy, its utility is potentially limited in the face of acidosis and thrombocytopenia.(34–36) As such, these derangements should be aggressively corrected simultaneous with (or even prior to) rFVIIa administration.

WHAT IS THE ROLE FOR CRYOPRECIPITATE TRANSFUSION?

Cryoprecipitate is derived from the precipitate fraction of cold-thawed human plasma. By far, it is the richest, most concentrated source of fibrinogen available in the United States. A standard ten unit bag of cryoprecipitate contains 2.5 g of fibrinogen while an entire bag of fresh whole blood contains only 1.0 g and fresh frozen plasma a mere 0.40 g unit bag.(37) The importance of this among patients receiving massive transfusion lies in the fact that fibrinogen is the first component of human clotting to decrease to pathophysiologic levels in hypocoagulable patients with major blood loss.(38) This hypofibrinogenemia does not seem to be completely explained by blood loss and resuscitation alone and appears to be the result of (or at least exacerbated by) hypoperfusion, acidosis, and hypothermia. While fibrinogen levels are likely maintained within normal limits when more aggressive ratios of PRBC: plasma are used, it is common to see their values diluted or consumed when crystalloid and PRBC dominate the resuscitation. Therefore, we would recommend using plasma to maintain fibrinogen values above 150 mg/dL during the massive transfusion process. However, once hypofibrinogenemia develops, as it has in this patient, treatment should be focused at the restoration of values to greater than 100 mg/dL (preferably greater than 150 mg/dL).(6) Stinger et al. have shown that increased fibrinogen levels are associated with improved survival in massively transfused casualties.(37)

WHAT IS THE ROLE FOR PLATELET TRANSFUSION?

Thrombocytopenia in trauma generally results from increased platelet destruction and dilutional causes, both of which are common during transfusion for massive blood loss.(38) Surgical bleeding due solely to thrombocytopenia does not generally occur until platelet counts have fallen below 50,000/mL, while coagulopathy and shock may increase the spontaneous bleeding risk with platelet counts

less than 80,000/mL associated with bleeding. Unfortunately, 75% of patients transfused with 20 or more red blood cell units in the first 24 h will develop platelet counts less than 50,000/mL. In this patient population, empiric transfusion may be required it may be necessary to request platelets at levels above the desired target to ensure their availability when needed. In this particular patient, with an absolute platelet count greater than 80,000/mL, surgical bleeding controlled, and massive transfusion process completed, we would recommend addressing the fibrinogen, hypothermia, and elevated INR and hold on transfusing platelets at this time. Johansson and colleagues have shown that increased use of platelets in the OR, resulting in platelet counts > 100,000, improved survival of ruptured aneurysm patients.(39)

> An 80-year-old male on warfarin for atrial fibrillation is transported to the Emergency Department after sustaining a fall from a ladder. His Glasgow Coma Scale (GCS) is 13. A stat CT of the head is obtained which reveals an intracerebral hemorrhage. A neurosurgical consultation is obtained immediately and he is transported to the Trauma ICU. Laboratory values are pending.

Traumatic brain injury (TBI) results in coagulopathy and thrombocytopenia through a variety of mechanisms and this population of patients should be assumed to have some level of clotting disturbance at presentation. The prevalence of thrombocytopenia or coagulopathy in severe TBI has been reported as high as 90% with prevalence in the less injured (moderate TBI) as high as 33%.(40, 41) The brain contains a high concentration of tissue thromboplastin which activates the extrinsic clotting cascade and fibrin clot is formed. In addition to the consumptive coagulopathy that follows the release of tissue thromboplastin, damaged cerebral endothelium activates platelets and the intrinsic clotting cascade with further depletion of clotting factors and consumption of platelets. Shortly thereafter, plasmin is activated, which results in fibrinolysis and clot dissolution.

Among patients 55 years of age or older who sustain TBI, 5–10% will be taking warfarin at the time of admission. This population appears to have a higher frequency of isolated TBI, more severe injury, and a higher probability of death.(42) In addition, the risk of mortality in TBI patients with concomitant warfarin use increases dramatically with an increase in age and increase in INR. As such, these patients should be approached fairly aggressively in the management of their anti-coagulation status.

One of the more common indications and uses of warfarin is in patients with atrial fibrillation. While proponents of anti-coagulation for atrial fibrillation point to the benefit of ischemic stroke prevention and "acceptable" rate of intracranial hemorrhage, the data supporting this stance excluded those patients at high risk for falls.(43, 44) The risk for intra-cranial hemorrhage in patients at low fall risk is 0.5 per 100 patient-years while that at high risk for falls is almost 3 per 100 patient-years. Given the risk of hemorrhage and death in patients taking warfarin, re-starting this agent following injury (in patients with a sole indication of

atria fibrillation) should be done with caution. Alternatively, in the patient without a mechanical valve indication for warfarin, the re-starting of this agent can be done as an outpatient by the physician who will be assuming their care.

> The patient's neurological status deteriorates and he is intubated. The patient's laboratory values return and his platelets are 209 and his INR is 2.5. What is the role of Vitamin K?

Warfarin inhibits the vitamin K-dependent synthesis of biologically active forms of the calcium-dependent clotting factors II, VII, IX, and X. Precursors of these factors require glutamic acid carboxylation to allow their respective clotting factors to bind the vascular endothelium. Reversal of anticoagulation has often been undertaken with the administration of Vitamin K. Given the potential for anaphylaxis with the intravenous solution and overcorrection with oral dosing, its use should be reserved for those with an INR of 4 or greater. In addition, a recent meta-analysis of randomized controlled trails and prospective cohort studies on the topic noted that oral and intravenous Vitamin K are equally effective in reducing 24-h INR to less than 4.0 in 75% of patients.(45) However, Vitamin K was ineffective for this indication when administered subcutaneously or if the patient was taking an oral anticoagulant other than warfarin. In cases such as with this patient where the INR is less than 4, Vitamin K should be withheld. Used alone, Vitamin K is largely ineffective in the rapid reversal of coumadin induced coagulation abnormalities.

WHAT IS THE ROLE OF PCC?

Prothrombin complex concentrate (PCC) is a combination of blood clotting factors (II, VII, IX, and X) that can be used to reverse the effect of warfarin. Two trauma studies have described effective PCC administration in reversing warfarin anticoagulation in the urgent setting and did so with less volume than traditional plasma based methods and was more "complete" in its reversal.(46, 47) Other studies have shown that its effects are as fast as rFVIIa and longer lasting. However, PCC should be administered along with Vitamin K and or fresh frozen plasma (FFP) as its effects on reversing warfarin are short lived.(47, 48) Only a few studies have evaluated PCC use in trauma patients, however, the effects seem fast, safe, and beneficial in this critically injured patient population and its use will likely increase.(49, 50)

WHAT IS THE ROLE OF FFP?

As one cannot rely on GCS, physical examination, or degree of anticoagulation to identify injured patients needing warfarin reversal, one must maintain a very high index of suspicion when evaluating this at-risk patient population. As such, many institutions have long used thawed plasma to rapidly address the patient with potential intra-cranial hemorrhage.(45) The aim of this approach is 2-fold: to treat the likely elevation of INR due to a tremendous release of tissue thromboplastin and to reverse possible warfarin anti-coagulation. Once patients have been found to have intra-cranial hemorrhage and history of warfarin identified, rapid

correction of abnormal coagulation function should be undertaken via to achieve a normal anticoagulation profile. Some authors have even demonstrated that complete anticoagulation reversal, within 4 h of presentation, is associated with a decreased risk of intra-cranial hemorrhage progression and a reduction in mortality.(46)

> After family arrives, a more complete history is obtained. In addition to atrial fibrillation, the patient has carotid artery disease and is on a "baby" aspirin (81 mg) and clopidogrel. Can aspirin and or clopidogrel be reversed?

The bleeding effects of aspirin are mediated through inhibition of cyclo-oxygenase. Inhibition of this enzyme leads to negative effects on platelet prostaglandin synthesis and an inhibition of catecholamine-induced vasoconstriction following injury. While several agents have been advocated to reverse the effects of aspirin (DDAVP, aprotinin, and platelet transfusions), none of these have been shown to be effective in any clinical trial. The most sensible therapy is supportive. The physician should aggressively treat any clotting factor deficiencies or abnormalities. As for the platelet inhibition itself, one need only to minimize intervention or insult and cautiously await the 4–5 days required until the irreversible effects of aspirin-mediated bleeding tendency have passed (as new, effective platelets enter the circulation).(51)

Clopidogrel selectively and irreversibly inhibits adenosine diphosphate-induced binding of fibrinogen to platelets and inhibits platelet aggregation in response to collagen, thrombin, and shear stress. Like aspirin, clopidogrel causes a prolongation of bleeding time and a delay in clot retraction and does so for the duration of the platelet's lifespan.(52) Also like aspirin, there is no "antidote." Though some would advocate the use of platelet transfusions in those on clopidogrel, the only truly effective therapy is one of time. Recently, however, Altman and colleagues noted that rFVIIa reversed the inhibitory effect of aspirin and clopidogrel on in vitro thrombin generation. While this has not yet been demonstrated in vivo, rFVIIa may serve as a useful adjunct for emergent control of bleeding in patients receiving antiplatelet medications.

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Grading Scheme

The grading scheme classifies recommendations as strong (grade 1) or weak (grade 2), according to the balance among benefits, risks, burdens, and possibly cost, and to the degree of confidence in estimates of benefits, risks, and burdens. The system classifies quality of evidence as high (grade A), moderate (grade B), or low (grade C) according to factors that include the study design, the consistency of the results, and the directness of the evidence.

1A/strong recommendation, high-quality evidence
1B/strong recommendation, moderate-quality evidence
1C/strong recommendation, low-quality or very low-quality evidence
2A/weak recommendation, high-quality evidence
2B/weak recommendation, moderate-quality evidence
2C/weak recommendation, low-quality or very low-quality evidence

Borgman et al. noted an eightfold reduction in mortality by increasing the use of plasma in massively transfused trauma patients.(12)

2B/weak recommendation, moderate-quality evidence

Cotton and colleagues implemented a protocol to address exsanguinating hemorrhage in the most severely injured patients.(8) This protocol delivers red-blood cells, plasma, and platelets in an aggressive and predefined manner. The authors found a 74% reduction in the odds of mortality.

2B/weak recommendation, moderate-quality evidence

Holcomb et al. have recently published the results of a retrospective, multicenter study of massive transfusion in 16 Level 1 trauma centers. They found that increased plasma and platelets were associated with improved early and late outcomes.

1B/strong recommendation, moderate-quality evidence

Rapid rewarming has been shown to improve survival in hypothermic trauma patients.(16)

1B/strong recommendation, moderate-quality evidence

Once hypofibrinogenemia develops, as it has in this patient, treatment should be focused at the restoration of values to greater than 100 mg/dL (preferably greater than 150 mg/dL).

2C/weak recommendation, low-quality or very low-quality evidence

Johansson and colleagues have shown that increased use of platelets in the OR, resulting in platelet counts >100,000, improved survival of ruptured aneurysm patients.(36)

2B/weak recommendation, moderate-quality evidence

Given the potential for anaphylaxis with the intravenous solution and overcorrection with oral dosing, vitamin K should be reserved for those with an INR of 4 or greater.

2B/weak recommendation, moderate-quality evidence

Some authors have demonstrated that complete anticoagulation reversal, within 4 h of presentation, is associated with a decreased risk of intracranial hemorrhage progression and a reduction in mortality.(43)

2C/weak recommendation, low-quality or very low-quality evidence

Only a few studies have evaluated PCC use in trauma patients, however the effects seem fast, safe and beneficial in this critically injured patient population and its use will likely increase.(49, 50)
2B/weak recommendation, moderate-quality evidence

41 Adrenal insufficiency in critical illness
Carrie A Sims and Vicente Gracias

A 40-year-old male with rheumatoid arthritis on chronic pred-nisone (5 mg/day) presents to the Emergency Department in septic shock due to perforated diverticulitis. His blood pressure is 90/45 mmHg with a heart rate of 120 bpm. The patient receives broad spectrum antibiotics and aggres-sive fluid resuscitation. His hemodynamics improve and he is brought emergently to the operating room. Prior to induction, the anesthesiologist gives the patient 100 mg of hydrocortisone. The patient undergoes a sigmoid resec-tion with diverting colostomy and is brought to the surgi-cal intensive care unit (SICU). Postoperatively, the patient receives three additionally doses of hydrocortisone, but is transitioned to his home dose of steroids on postoperative day 2. On postoperative day 7, the patient is transported to the SICU in septic shock. He is emergently intubated with etomidate. He is aggressively resuscitated and broad spectrum antibiotics are initiated. Despite aggressive resus-citation, he has an increasing vasopressor requirement. A cosyntropin stimulation test is performed and he is started on "stress dose" steroids for "relative adrenal insuf-ficiency". His hemodynamics improve and the vasopressors are weaned. An intra-abdominal abscess is diagnosed and drained by interventional radiology. The patient improves and is discharged to home on postoperative day 20.

ADRENAL INSUFFICIENCY

Pathophysiology

Decreased or inappropriate cortisol secretion is the hallmark of adrenal insufficiency and can be caused by a variety of deficien-cies in the hypothalamic–pituitary–adrenal (HPA) axis. The signs and symptoms of adrenal insufficiency depend on the degree of adrenal reserve, the severity of physiologic stress, and whether or not mineralocorticoid production is preserved. In the ICU, adrenal insufficiency can be caused by defects or derangements at every level of the HPA axis.

Although primary adrenal insufficiency in the intensive care unit is rare, it can result from diseases acutely affecting the adre-nal gland such as bilateral adrenal hemorrhage or infarction secondary to trauma, coagulopathy, thromboebolic disease, or sepsis (e.g., Waterhouse–Friderchsen syndrome). Additionally, a number of drugs frequently used in the critically ill can cause adrenal insufficiency either by inhibiting cortisol biosynthesis (e.g., etomidate, ketaconazole) or by accelerating its metabolism (e.g., phenytoin, barbituarates, rifampin).(1–5)

Secondary adrenal insufficiency can be caused by any disease process or medication that interferes with adrenocorticotropic hormone (ACTH) secretion. Direct damage to the pituitary gland from infection, head trauma, hemorrhage, or infarction can present as adrenal insufficiency, but an isolated ACTH deficiency is rare.(6) Most often disease states that result in decreased ACTH secretion occurs in the context of other pituitary hormone deficiencies and dysfunction may be difficult to identify.(7)

Therapeutic glucocorticoid use is the most common cause of drug-induced secondary adrenal insufficiency. Exogenous ster-oids result in suppression of the hypothalamic-pituitary axis with atrophy of ACTH producing cells. Secondary insufficiency can occur when glucocorticoid therapy is tapered or the physi-ologic stress exceeds the anticipated glucocorticoid requirement. Chronic high dose steroid use can also result in decreased corti-cotropin-releasing hormone (CRH) secretion from the hypotha-lamus. Without the ACTH-secretagogue action of CRH on the anterior pituitary, ACTH levels decline, endogenous cortisol levels fall, and the adrenal glands atrophy.

Interestingly, unlike primary adrenal insufficiency in which the entire adrenal gland is dysfunctional, the mineralocorticoid secretion in secondary and tertiary adrenal insufficiency is pre-served. Because mineralocorticoid secretion depends primarily on the renin–angiotensin system rather than ACTH stimulation, the adrenal glands are capable of producing adequate levels of aldosterone even in the setting of cortisol deficiency.(8)

Critically ill patients may also develop a state of relative adrenal insufficiency or acquired glucocorticoid resistance. Although the pathophysiology of this form of adrenal "insufficiency" remains poorly understood, critical illness may alter the HPA axis and downregulate feedback responses. The stress of critical illness is associated with high circulating cortisol levels and often there is a blunted response to ACTH. Supplemental hydrocortisone may improve the hemodyanamic instability in septic shock suggesting a relative shortage of steroids or a downregulation of available receptors.(9) Currently, it is unclear if the diagnosis of relative adrenal insufficiency represents a physiologic state or a pharma-cological phenomenon.

Signs and Symptoms of Adrenal Crisis

Patients with acute life-threatening adrenal insufficiency typi-cally present with severe hypotension or hypovolemic shock. The degree of mineralocorticoid deficiency directly corre-lates with the degree of cardiovascular collapse and patients who are receiving glucocorticoid supplementation can develop an adrenal crisis if their mineralocorticoid require-ments are not met.(10) Patients with acute adrenal insuf-ficiency will frequently present with nonspecific symptoms such as abdominal pain, nausea, vomiting, fever, lethargy, and mental status changes. Because the symptoms of acute adre-nal crisis are similar to those found in overwhelming sepsis, the proper diagnosis can be elusive. Hyponatremia is com-mon, whereas hyperkalemia only occurs if mineralocorticoid

production is not preserved (e.g., primary adrenal insufficiency). Finally, hypoglycemia certainly can occur but is rare and more frequently occurs in the setting of secondary adrenal insufficiency.(19)

Because an acute adrenal crisis can rapidly progress to death, patients who are suspected of adrenal insufficiency should be immediately given 100 mg of intravenous hydrocortisone followed by 100–200 mg/day. Aggressive resuscitation with isotonic intravenous fluids is necessary to treat the underlying hypovolemia.(16) Although treatment should not be delayed pending diagnostic evaluation, it is prudent to draw baseline blood samples for cortisol and ACTH prior to hydrocortisone administration.

Should "Stress-Dose" Steroids Be Used in Patients on Chronic Steroids Prior to Surgery?

The stress of major surgery and anesthesia stimulate the HPA axis to increase the production of glucocortioids. Over time, supraphysiologic doses of glucocorticoids can suppress the HPA axis. Patients who are chronically treated with steroids may not be able to mount an appropriate adrenal response to the stress of surgery or critical illness and an increased dose of steroids may be necessary in order to simulate the expected increased requirement.

The current practice of giving perioperative "stress–dose" steroids became routine after two case reports published in the 1950s reported unexpected post-operative deaths in young patients receiving long-term glucocorticoid therapy. Although never proven biochemically, these unanticipated deaths were attributed to adrenal insufficiency.(11, 12) Recently, this practice has been called into question with several studies demonstrating no clinical detriment associated with not giving additional steroids perioperatively.(13–16) These studies, however, were small, heterogeneous and underpowered.

Diagnosing decreased adrenal reserve perioperatively can be problematic. A blunted response to ACTH stimulation does not necessarily correlate clinically with the development of adrenal insufficiency and the degree of HPA suppression cannot be accurately predicted by the duration or amount of corticosteroids. (17) Moreover, there is considerable variability in the return of normal HPA axis activity following the cessation of glucocorticoid therapy with normal recovery returning within 2 days to 12 months.(18)

Given the potential benefit and relatively little risk associated with short-term "stress dose" steroids, it is currently recommended that perioperative steroid supplementation be given to patients who have been treated with long-term steroids within the last year (>5 mg/day of prednisone or an equivalent).(19) Because the HPA axis may not recover for up to 12 months, supplemental steroids should be given to patients who have stopped long-term steroids within the past year. The traditional dose of 100 mg of hydrocortisone every 8 h, however, exceeds the physiologic response to major surgery and is excessive. The current consensus recommends giving much lower doses of steroids based on the degree of surgical stress and with a rapid taper over 1–3 days (Table 41.1).(20) This strategy is designed to recapitulate the normal response to surgical stress while minimizing the effects of high-dose steroids.

Table 41.1 Recommendations for Peri-operative Hydrocortisone Supplementation for Patients on Long-term Steroid Therapy.

Surgery Type	Stress Dose	Duration*
Minor (eg, inguinal herniorrhaphy)	25 mg/day	1 day
Moderate (eg, total joint replacement)	50–75 mg/day	1–2 days
Major (eg, cardiopulmonary bypass)	100–150 mg/day	2–3 days

* In the absence of complications
Salem M et al.(20)

How Do You Diagnose Adrenal Insufficiency?

The initial diagnostic evaluation for adrenal insufficiency includes measuring morning plasma ACTH and serum cortisol values. A morning cortisol level below (100 nmol/L or 3.6 μg/dL) indicates adrenal insufficiency whereas a value greater than (500 nmol/L or 18 μg/dL) suggests an intact HPA axis.(16) Although severe hypofunction of HPA axis is usually associated with subnormal plasma cortisol values, a low basal level is not sufficient to make the diagnosis adrenal insufficiency and dynamic testing is required. In general, primary adrenal insufficiency can be distinguished from secondary disease by elevated plasma ACTH levels.

Although the insulin tolerance test and the overnight metyrapone test have been used in the past, the ACTH stimulation test is currently used most frequently to assess adrenocortical responsiveness.(16) This "stimulation test" is performed by giving 0.25 mg of cosyntropin, a synthetic analogue of ACTH. Cortisol levels are measured pre-cosyntropin and 30–60 minutes following intravenous cosyntropin dosing. In normal, nonstressed individuals, the basal cortisol level will almost double following cosyntropin stimulation provided that the basal level does not exceed the normal range. A subnormal response (<500 nmol/L or <18 μg/dL) is considered a positive test result and is suggestive of adrenal insufficiency.(21) In patients that are septic and physiologically stressed, a state of a "relative adrenal insufficiency" has been described when patients fail to increase their cortisol levels by > 9μg/dL.(22)

Diagnosing adrenal insufficiency can be difficult, especially in the setting of critical illness. Cortisol immunoassay used in healthy patients may underestimate cortisol levels in the critically ill because these assays measure *both* protein-bound cortisol and biologically active free cortisol. With critical illness, serum protein concentration decrease significantly. Because more than 90% of serum cortisol is protein bound, the measured total cortisol level may be low, giving the appearance of adrenal insufficiency, even though free cortisol levels may be appropriate.(23) Currently, measuring free cortisol is clinically challenging and not routinely available.

When Should Steroids Be Used in the Management of Sepsis?

The use of corticosteroids in severe sepsis may be beneficial, but remains controversial. In patients with vasopressor-unresponsive septic shock, one randomized controlled trial demonstrated that corticosteroid replacement therapy reduced the duration of vasopressor support and improved survival in patients with relative

adrenal insufficiency.(22) Two large meta-analysis investigating steroid supplementation in sepsis supported these findings.(24, 25) Recently, however, the benefits of steroids haves been called into question. In a large, randomized multi-institutional study, corticosteroid supplementation accelerated shock reversal (CORTICUS), but did not improve overall survival.(26) The discrepancy in survival benefit between the Annane et al. study and the CORTICUS trial may reflect differences in patient acuity and timing of enrollment. Patients in the Annane et al. study also received fludrocortisone in addition to hydrocortisone supplementation.(22) Whether or not the addition of a mineralocorticoid such as fludrocortisone improves survival is currently under investigation. According to the 2008 Surviving Sepsis Campaign guidelines, hydrocortisone (< 300 mg/day) may be used in septic shock that is refractory to fluid and vasopressor support.(27) Because dexamethasone results in an immediate and prolonged suppression of the HPA axis, hydrocortisone should be used preferentially. Supplemental steroids should be tapered when vasopressors are no longer required in order to minimize side effects including the risk of developing secondary adrenal suppression.

Is a Cosyntropin Stimulation Test Necessary Prior to Initiating Steroid Therapy?

Previously, a cosyntropin stimulation test was advocated prior to instituting steroid therapy in order to assess the potential benefit of steroids in septic patients. It was suggested an increase in cortisol of ≤ 9 μg/dL within 30–60 minutes following the administration of cosyntropin (0.25 mg) was reflective of "relative adrenal insufficiency." Accordingly, it was suggested that these patients were more likely to benefit from exogenous steroids than those that responded with an increase of > 9 μg/dL in serum cortisol.(22) Although this definition of "relative adrenal insufficiency" has gained wide acceptance, the distinction based on cosyntropin response may not be clinically relevant. In the Annane et al. study, the overall trial population benefited from steroids regardless of cosyntropin response. More recently, the multicenter CORTICUS trial demonstrated that steroids hastened the resolution of shock, but did not improve survival, regardless of cosyntropin response.(26) As such, a cosyntropin stimulation test is no longer recommended as a method for determining which patients should receive hydrocortisone supplementation.(27)

How Long Should Replacement Steroids be Continued?

In order to minimize the potential side effects associated with steroid supplementation, steroids should be tapered rapidly. Perioperative "stress dose" steroid use should be proportional to the surgical stress and de-escalated to the patient's maintenance dose within 1–3 days postoperatively (Table 41.2). If steroids are used to treat refractory septic shock, it is recommended that they be weaned when vasopressors are no longer required.(27) Although the overall benefit of tapering versus abrupt cessation of steroids has not been directly investigated, a rebound hemodynamic and immunologic phenomenon has been described with the abrupt discontinuation of corticosteroids in one crossover study.(28) As such, it seems prudent to taper steroids over several days following the resolution of vasopressor-dependent shock.

Table 41.2 Evidence-based Recommendations for the Diagnosis and Treatment of Adrenal Insufficiency in Critical Illness.

- In cases of suspected adrenal insufficiency, administer 100 mg IV hydrocortisone followed by 100–200 mg/day. Consider drawing baseline samples for cortisol and ACTH prior to hydrocortisone supplementation. (LEVEL 1C)
- "Stress dose" steroids should be given to patients who have been treated with ≥ 5mg/day of prednisone (or equivalent) for more than 2 weeks in the last year. (Level 1C)
- The dose of "stress steroids" should be based on the degree of anticipated surgical stress and should be tapered rapidly over 1 to 3 days. (Level 1C)
- Hydrocortisone (<300 mg/day) may be used in septic shock that is refractory to fluid and vasopressor support, but supplemental steroids should be tapered when vasopressors are no longer required (Level 1B). Fludrocortisone (50 μg/day) may also be given (Level 2A).
- Dexamethasone results in an immediate and prolonged suppression of the HPA axis and should not be used (Level 1C).
- A cosyntropin stimulation test should not be used to determine which patients in septic shock should receive hydrocortisone supplementation (Level 1C).
- Etomidate should not be used in the critically ill. (Level 1B)

What Is the Role of Mineralocorticoids in the Treatment of Septic Shock?

While the degree of mineralocorticoid deficiency directly correlates with cardiovascular collapse in adrenal crisis, insufficient mineralocorticoid secretion may also play role in septic shock. Many critically ill patients demonstrate adrenocortical dysfunction with decreased aldosterone secretion despite appropriately elevated cortisol levels.(29) Furthermore, inappropriately low aldosterone levels in critical illness may contribute to increased mortality. In prospective, observational study, critically ill patients with an aldosterone/renin ratio of < 2 were at increased risk of dying when compared to similar patients with a ratio of ≥ 2 (75% vs. 46%, $p < 0.001$).(30) Because hydrocortisone has mineralocorticoid activity, the benefit of adding fludrocortisone in sepsis is unclear. Nonetheless, oral fludrocortisone (50 μg daily) has been used in conjunction with hydrocortisone to treat sepsis and is considered an optional therapy in the Surviving Sepsis Campaign 2008 guidelines.(22, 27)

What Is the Impact of Etomidate an Adrenal Function?

Etomidate is widely used as an IV induction agent during endotracheal intubation because of its favorable safety profile and its relative cardiovascular stability.(31) Unfortunately, one potential adverse effect associated with its use is decreased corticosteroid production. Etomidate temporarily inhibits 11 beta hydroxylation in the adrenal gland and decreases steroidogenesis.(32) Following a single induction dose of etomidate, there is a significant but transient decrease in adrenocortical function in otherwise healthy patients which can last up to 24 h.(33) Despite causing a transient decrease in cortisol levels, etomidate does not appear to produce a persistent functional suppression or overt clinical adrenocortical insufficiency when used in the elective surgical setting.(34) When used as a continuous infusion for long-term sedation, however, etomidate has been associated with increased mortality.(35)

Because trauma, surgery and sepsis are characterized by an increase in cortisol production, the practice of using etomidate as a routine induction agent in critically ill patients has recently been questioned. Although there are no studies evaluating the impact of etomidate induction on outcomes in the critically ill, it is clear that patient's who receive etomidate for emergent intubation are unable to mount an appropriate response to cosyntropin stimulation.(36, 37) In a subgroup analysis of septic patients treated with low dose corticosteroids, Annane et al. identified 72 patients who had received etomidate for induction. Sixty-eight of these patients failed to respond appropriately to a cosyntropin stimulation test. Moreover, patients in this subgroup who subsequently received placebo rather than corticosteroids had significantly higher ICU and hospital mortality rates (75.5% vs. 54.8%, $p = 0.0315$).(38) Similar findings were reported in the CORTICUS trial.(26) Etomidate may have a negative impact on survival in critical illness and should not be used in patients with severe sepsis.(39) Although etomidate induced adrenal insufficiency can be reversed by giving supplemental steroids, it is prudent to avoid using etomidate in preference of alternative forms of sedation.(40, 41)

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42 Sepsis
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An 80-year-old woman presents to the Emergency Department with fever and right upper quadrant pain. Ultrasonographic evaluation reveals acute cholecystitis. Her systolic blood pressure is 70 mm/Hg as is her heart rate; her temperature is 40°C and her white blood count is 30,000/mm³. She had many prior myocardial infarctions and occasionally requires home oxygen for chronic obstructive pulmonary disease. The patient is given two 1 L boluses of crystalloid. Blood cultures are obtained, and she is started on broad spectrum antibiotics to cover biliary and enteric flora. Despite this, the patient has a systolic blood pressure of 80 mm/Hg. A central venous catheter is placed and the patient is started on norepinephrine and transferred to the surgical intensive care unit. Upon arrival, the patient is in worsening respiratory distress and she is intubated. An arterial line is placed at this time, and the norepinephrine drip is titrated to maintain a mean arterial blood pressure of 65. The patient's central venous pressure (CVP) is 4 and her hematocrit comes back at 25%. Her ScVO$_2$ is 63% and her lactate is 5 mmol/L. The patient is transfused with two units of blood and the interventional radiologist team is consulted to place a percutaneous cholecystostomy. Twelve hours after the procedure, the patient is requiring 25 mcg/min of norepinephrine, and she is started on activated protein C. Four days later, the patient is off of pressors and is afebrile with a normal white blood cell count. However, she is fluid overloaded, and she fails her spontaneous breathing trial. Two days later, she spikes a new temperature to 39°C, has a new infiltrate on chest X-ray, and has to go back on norepinephrine. New blood cultures and a bronchoalveolar lavage are obtained and her antibiotics are broadened to cover for new onset ventilator-associated pneumonia. Two days later, her cultures grow out methicillin-resistant Staphylococcus aureus. The patient is continued on gram negative and anaerobic coverage for her biliary sepsis and gram-positive antibiotic coverage for her pneumonia. The patient's pressors are weaned to off 2 days later. On ICU day number 10, the patient receives a tracheostomy for an inability to be weaned from the ventilator. After a 3-week hospitalization, she is tolerating weaning trials and is transferred to a rehabilitation facility with her cholecystostomy tube still in place.

WHAT IS THE DEFINITION OF THE SYSTEMIC INFLAMMATORY RESPONSE SYNDROME (SIRS), SEPSIS, SEVERE SEPSIS, AND SEPTIC SHOCK?

SIRS is the body's response to a variety of clinical insults.(1) SIRS is defined by changes in body temperature, heart rate, respiratory rate, and white blood cell count with at least two abnormalities needed to meet diagnostic criteria (Table 42.1). Sepsis is SIRS caused by infection. A total of 750,000 people develop sepsis annually in the United States with 215,000 people dying of the disease.(2) Sepsis exists along a continuum of clinical significance ranging from sepsis to severe sepsis to septic shock. Severe sepsis is defined as sepsis complicated by organ dysfunction, while septic shock is defined as sepsis with persistent hypotension and tissue hypoperfusion despite adequate fluid resuscitation.(1)

The definitions of SIRS and sepsis are both non-specific. Despite the obvious limitations in their diagnostic criteria, the definitions of both SIRS and sepsis have not been modified since their original description in 1992. Although numerous biomarkers have been associated with sepsis, none is sufficiently specific to alter the definition or to be routinely part of the diagnosis of the disease. A recent consensus conference to update the definition of sepsis suggested that while host genetic predisposition and host response on a molecular and cellular level may be useful in the future, they did not recommend any changes in the definition of sepsis, severe sepsis or septic shock.(3)

> The patient was in septic shock requiring pressor support despite adequate fluid resuscitation.

WHAT SORT OF BLOODWORK/ CULTURES SHOULD BE SENT?

When sepsis is suspected, both routine laboratory work (complete blood count, basic metabolic profile, other tests as indicated) and cultures should be drawn as soon as is practicable. The types of cultures sent are dependent upon the possible source of sepsis. Cultures can be sent from blood, sputum, urine, wound and indwelling drains, and catheters. The decision for what to send for culture is dependent upon the patient's history and a thorough physical exam. Sending "pancultures" without examining

Table 42.1 Definition of SIRS (patient must have ≥ 2 of the following).

Parameter	Abnormality
Body temperature	> 38°C or < 36°C
Heart rate	> 90 beats/min
Respiratory rate	> 20 breaths/min or PaCO$_2$ < 32 mmHg
White blood cell count	> 12,000 cells/mm³ or < 4,000 cells/mm³ or > 10% immature neutrophils

Source: Ref (1)

the patient is not appropriate, and frequently results in sending unnecessary and costly tests that are both low yield and unlikely to change clinical management.

Regardless of where cultures are sent from, cultures should be drawn prior to initiation of antibiotic administration as sterilization can occur within a few hours of drug delivery.(4) However, delays in initiation of antibiotic therapy are associated with increased mortality in sepsis; therefore, cultures should be drawn rapidly and antibiotic therapy should also be initiated rapidly. This should include at least two blood cultures.(5) Some experts recommend that at least one culture should be percutaneous and one culture should be sent from any indwelling vascular access that has been in place for more than 48 h.(4) This may be helpful if cultures drawn through the vascular device become positive more than 2 h earlier than the peripheral blood culture.(6) However, this is only helpful if an institution's microbiology laboratory has the ability to reliably report this information. If this cannot be done, drawing two peripheral blood cultures is a reasonable alternative, especially since many inexperienced clinicians will treat catheter colonization (a positive blood culture drawn through an indwelling device in the absence of a positive peripheral blood culture) without evidence of systemic bacteremia.

Although the exact types of cultures to send may be obvious from a history and physical, the possible sources of sepsis are frequently not clear, in which case culturing more broadly may be appropriate. In the common instance when the diagnosis of ventilator-associated pneumonia is entertained, the most appropriate method for obtaining cultures is unclear. Historically, bronchoalveolar lavage has been reported to be more accurate than tracheal aspirate.(7–9) However, a recent multicenter prospective randomized trial of 740 patients found that patients diagnosed with ventilator associated pneumonia with either bronchoalveolar lavage or tracheal aspirate had similar mortalities, lengths of stay and antibiotic use, (10) although the results are potentially limited by the exclusion of resistant organisms and immunocompromised patients from the study.(11) If a bronchoalveolar lavage is sent, quantitative cultures should be obtained as the number of organisms recovered should guide whether or not a clinician treats a positive culture.(12)

WHAT IS APPROPRIATE ANTIBIOTIC THERAPY AND SOURCE CONTROL?

Broad-spectrum antibiotic therapy in a presumed septic patient must be initiated promptly and directed toward all pathogens that are reasonable causes of sepsis. This is imperative because both inappropriate delays in the administration of antibiotics and inappropriately narrow spectrum antibiotics lead to increased mortality in sepsis. Specifically, it has been demonstrated that there is an increase in mortality for every hour of delayed antimicrobial treatment.(13) Additionally, when initial antibiotic therapy is not active against the pathogen causing sepsis, this is functionally equivalent to not starting antibiotics and is associated with a higher mortality.(14–17) This mortality difference persists even if appropriate antibiotics are initiated greater than 24 h after therapy was begun.(18) Although most septic patients will already have adequate intravenous access, if this is not the case, additional access should be established rapidly to assure that this is not a roadblock to antibiotic administration.

Empiric antibiotic therapy should have activity against all possible bacterial or fungal pathogens that might reasonably be the source of sepsis. The notion of "reasonable" is something that must be decided by the clinician based upon the pathogens that cause sepsis in the site being considered. At a minimum, this will typically include gram-positive and gram-negative bacterial coverage. The decision to specifically cover methicillin-resistant *Staphylococcus aureus*, anaerobic bacteria, fungi, and atypical pathogens should be made based upon both what type of infections occur in the body cavity where sepsis is suspected of arising from as well as the antibiogram of the treating institution. The antimicrobial therapy chosen should have adequate tissue penetration and be dosed in a manner that accounts for hepatic and renal metabolism and volume of distribution. Combination therapy should be considered in patients with suspected/known *Pseudomonas aeruginosa* infections or with neutropenia although this recommendation is primarily based on *in vitro* data.(4, 12, 19)

While *initial* antimicrobial therapy should be broad, once culture and susceptibility results are available, treatment should be narrowed as much as possible by either discontinuing or tailoring treatment to cover the offending organism(s). (4, 12) This requires daily reassessment of the patient's culture results. The length of antimicrobial treatment depends upon the source of infection. As a general estimate, bloodstream infections need to be treated for at least 2 weeks (5–7 days for uncomplicated *Staphylococcus epidermidis* infections), intra-abdominal infections and pneumonia should receive a 7-day course of treatment, and uncomplicated urinary tract infections should be treated for 3–7 days.(20–23) It is important to emphasize that these are estimates, and individual patients may require longer or shorter courses of therapy based upon their clinical status. If a non-infectious source is determined to be the cause of the patient's clinical status, antimicrobial therapy should be terminated. However, it is has been estimated that greater than half of patients with severe sepsis or septic shock will have negative blood cultures. If cultures come back negative but the clinician believes the patient is septic, additional investigation should be done to search for the source of sepsis. The decision to continue, stop, or change antibiotics in this circumstance should be made on a case-by-case basis.

While antibiotics can be curative in certain circumstances (i.e., pneumonia), antimicrobial therapy is adjunctive to definitive source control in circumstances where the septic source remains in the patient and is amenable to drainage, debridement, or device removal (i.e., abscess, infected central venous catheter, etc.). When source control is required, this should be instituted rapidly in the least invasive fashion that is physiologically effective.(24)

The patient was initially started on broad-spectrum antibiotic therapy to cover biliary and enteric flora. The patient improved with this; however, she then began showing signs of a new ventilator associated pneumonia for which she underwent bronchoalveolar lavage and had her antibiotics broadened.

WHAT MONITORING IS APPROPRIATE?

The amount of monitoring needed for a septic patient is proportional to the severity of sepsis. In cases of sepsis without significant hemodynamic compromise, monitoring should include (at a minimum) regular checks of heart rate, blood pressure, respiratory rate, temperature, and urine output. In patients with severe sepsis, standard monitoring should include all of the above plus continuous heart rate monitoring, pulse oximetry, and bladder catheterization for more frequent urine output monitoring in those patients who produce urine. For patients with septic shock, all of the above should be used in addition to placement of an arterial line for continuous blood pressure monitoring. Additionally, the vast majority of patients in septic shock require a central venous catheter for measurement of CVP, and delivery of pressors, fluids, antibiotics as well as multiple blood draws. There is some evidence that a central venous catheter that can continuously monitor central venous oxygen saturation ($ScVO_2$) may be helpful in guiding resuscitation (see below).

In "routine" cases of septic shock, there is no evidence that additional invasive monitoring is beneficial. Specifically, prospective randomized trials on the usage of pulmonary artery catheters have not shown improved outcomes in either high risk surgical patients or acute respiratory distress syndrome (ARDS) patients. (25, 26) Nonetheless, in selected patients with complex cardiopulmonary disease, placement of a pulmonary artery catheter may be helpful in guiding therapeutic management. Additionally, less invasive alternatives such as esophageal Doppler and continuous arterial cardiac output monitoring may play a role in the management of complex patients with septic shock although data supporting their widespread usage is lacking. Although not continuous in nature, transesophageal echocardiography may also yield substantial "snapshot" insights into a patient's cardiopulmonary status at a given timepoint.

> The patient had a central venous catheter and arterial line placed to assist with management of her septic shock. A pulmonary artery catheter was not placed, although it could have been considered if the patient did not respond to therapy in light of her significant comorbidities.

WHAT ARE THE END POINTS OF RESUSCITATION IN SEPTIC SHOCK PATIENTS AND HOW DO YOU GET TO THAT POINT (FLUIDS, PRESSORS, INOTROPES)?

Similar to "the golden hour" in trauma or the rapid initiation of antibiotic therapy, the timing of resuscitation in septic shock has been demonstrated to be a critical determinant of survival in severe sepsis and septic shock. A single center prospective, randomized trial of 263 patients demonstrated a marked improvement in hospital mortality (30.5% vs. 46.5%) in patients that received early goal-directed therapy in the first six hours of their hospitalization.(27) Patients randomized to receive early goal-directed therapy were bolused with 500 ml of crystalloid every thirty minutes until their CVP was 8–12 mmHg. If patients had a mean arterial pressure (MAP) less than 65 mmHg they were

begun on vasopressors. The goal $ScVO_2$ was ≥ 70%. If the central venous oxygen saturation was less than this level, red blood cells were transfused until a patient's hematocrit was greater than 30%. If after optimization of CVP, MAP and hematocrit, the $ScVO_2$ was still less than 70%, dobutamine was then started at a dose of 2.5 µg/kg/min and increased by 2.5 µg/kg/min every 30 minutes up to a maximal dose of 20 µg/kg/min.

While there are definite limitations to using CVP and $ScVO_2$ as end points for resuscitation, early goal directed therapy to treat septic shock (where fluid-resistant hypotension or a lactate concentration ≥ 4 mmol/L are surrogates for tissue hypoperfusion) can easily be protocolized to treat septic patients (Table 42.2).(4, 27–31) Of note, fluid challenges should be discontinued when goal cardiac filling pressures are achieved and the patient's hemodynamics are no longer improving with boluses. Additionally, inducing supranormal oxygen delivery has not been demonstrated to improve outcomes in patients with septic shock and should therefore not be a goal of resuscitation.(32, 33)

There is no evidence that using crystalloids or colloids for fluid resuscitation changes mortality in septic patients. However, in a multicenter prospective randomized trial of 537 patients comparing 10% pentastarch to modified Ringer's lactate in patients with severe sepsis, 10% pentastarch (a colloid) was associated with higher rates of acute renal failure and need for renal replacement therapy, and the study was stopped early because of this. (34) Additionally, a multicenter prospective randomized trial comparing saline to albumin in 6997 patients demonstrated equivalent mortality when either fluid was used for resuscitation in a heterogeneous patient population, although subset analysis demonstrated that albumin is associated with a higher mortality in patients with traumatic head injury.(35, 36) Of note, crystalloids are less expensive than colloids but have a larger volume of distribution.

Either norepinephrine or dopamine may be used as first line to improve hemodynamics in patients with septic shock.(4, 37) It is important to remember that the endpoint of pressor use is

Table 42.2 Parameters for Early Goal Directed Resuscitation During Septic Shock.

Measured Parameter	Goal
CVP	8–12 mmHg
-if intubated or with preexisting decreased ventricular compliance	12–15 mmHg
MAP	≥ 65 mmHg
Urine output	≥ 0.5 ml/kg/hr
ScVO2 or SVo₂	≥ 70% / ≥ 65%
-if CVP goal obtained with fluid challenge but ScvO₂ or SVO₂ remains < goal	
Hematocrit	≥ 30%
Scvo₂ ≤ 70% or SVo₂ ≤ 65%	Dobutamine infusion beginning at 2.5 mcg/kg/h to maximum of 20 mcg/kg/h

Source: Ref (4, 27)

maintaining adequate tissue perfusion and not simply raising blood pressure. Thus, even though multiple pressors can successfully increase MAP, each has additional unwanted physiologic effects which must be considered when deciding which agent to use. Norepinephrine is more potent and less arrhythmogenic than dopamine; however, dopamine has increased inotropic effects and may be useful in patients with compromised systolic function.(38) Many septic shock patients have a relative vasopressin deficiency which previously led to substantial interest in the use of this agent to treat hypotension in septic shock.(39) Nonetheless, a multicenter prospective, randomized trial of 778 patients comparing mortality in patients with septic shock receiving low-dose vasopressin (0.03 units per minute) or norepinephrine as their primary pressor demonstrated similar mortality.(40) Based upon these results, vasopressin is not recommended as a first-line agent in septic shock but can be added to norepinephrine when the patient is refractory to high dose pressors. Neither epinephrine nor phenylephrine should be used as first-line agents because of less favorable hemodynamic profiles (tachycardia and decreased cardiac output respectively) than norepinephrine or dopamine although epinephrine may be added as a "rescue" therapy in patients refractory to other pressors. Of note, there is no evidence that patients treated with epinephrine do worse than those treated with norepinephrine and dobutamine. (4, 41) Although dopamine is an acceptable first-line agent for septic shock, low-dose ("renal dose") dopamine should not be used for its effects on the renal vasculature as studies have convincingly shown this does not improve outcome in renal failure.(42) The "typical" MAP goal in septic shock is 65 mmHg; however, the clinician needs to take into account the patient's clinical history, which can indicate a higher or lower goal may be required to maintain perfusion.(43) In patients with septic shock with a low cardiac output despite pressor support, dobutamine is the first-line agent (dosed as described above), with a main side effect of tachycardia.(4)

> The patient was initially treated with crystalloid boluses and started on a norepinephrine drip. When her ScVO$_2$ came back less than 70% and her hematocrit was less than 30%, she was transfused with two units of blood. All of these are consistent with early goal-directed therapy of sepsis.

WHAT IS THE ROLE OF ACTIVATED PROTEIN C?

Recombinant human activated Protein C (rhAPC) was the first biologic agent approved by the Food and Drug Administration (FDA) for the treatment of severe sepsis; however, its use is controversial. The initial phase III trial of rhAPC was a multicenter prospective, randomized trial in 1,690 patients which demonstrated a 6% absolute mortality reduction and 19% relative risk reduction with the use of rhAPC in septic patients.(44) This study was stopped early for efficacy in the treatment arm. Subgroup analysis demonstrated that all the benefit of rhAPC occurred in sicker patients (a 13% absolute mortality reduction), and the drug was subsequently approved by the FDA for usage in patients with Acute Physiology and Chronic Health Evaluation (APACHE) II scores ≥ 25. A subsequent single arm, open-label study of rhAPC

in severe sepsis showed similar mortality to the initial phase III study and also demonstrated that earlier use of the drug is associated with better outcomes.(45) However, consistent with the fact that all benefit in the initial trial was noted in sicker patients, an FDA-mandated follow-up multicenter prospective, randomized study of 2,613 patients with a lower risk of death failed to demonstrated a benefit to rhAPC and was stopped early for futility.(46) Of note, a multicenter prospective randomized trial of rhAPC in 399 pediatric septic patients also failed to show a benefit to the drug and was stopped early for futility.(47) An ongoing trial of rhAPC in 1,500 patients with septic shock (in contrast, only 65% of patients in the initial trial were in shock) should definitively clarify the role of the drug in septic shock.(48)

The role of rhAPC in surgical patients is also unclear. The relative risk reduction in mortality was lower in surgical patients in the initial study of rhAPC than the overall patient population, while subgroup analysis in the follow-up lower risk study showed a higher mortality in surgical patients with single organ failure who were treated with rhAPC.(4) A subsequent retrospective analysis of an international database of patients treated with rhAPC showed a 10.7% decrease in mortality in 1,659 surgical patients with APACHE II scores ≥ 25.(49)

The biggest risk with rhAPC use is bleeding (contraindications are listed in Table 42.3). The drug is generally not started within 12 h of surgery and is held for 2 h prior to any invasive procedure. The risk of serious bleeding ranges from 3.5 to 6.5% depending on the trial, with intracranial hemorrhage rates ranging from 0.2% to 1.5%.(44–46) Surgical patients treated with rhAPC have a greater proportion of serious bleeding events but most of these do not result in mortality. Despite the bleeding risk, patients simultaneously treated with rhAPC and prophylactic heparin to reduce venous thromboembolic disease had lower mortality

Table 42.3 Absolute and Relative Contraindications to rhAPC Therapy.

Absolute contraindications
- Active internal bleeding
- Hemorrhagic stroke within the prior 3 months
- Intracranial, intraspinal surgery, or severe head trauma within the prior 2 months
- Increased risk of life-threatening bleeding secondary to trauma
- Presence of an epidural catheter
- Intracranial neoplasm or mass lesion or evidence of cerebral herniation

Relative contraindications
- Concurrent *therapeutic* dosing of heparin to treat an active thrombotic or embolic event (prophylactic heparin is not a contraindication)
- Platelet count < 30,000 × 10^6/L. Note: increasing the platelet count by transfusion does not lessen the risk of rhAPC.
- INR > 3.0
- Gastrointestinal bleeding within prior 6 weeks
- Thrombolytic therapy within prior 3 days
- Oral anticoagulants or glycoprotein IIb/IIIa inhibitors within prior 7 days
- Aspirin usage at a dose of > 650 mg per day or other platelet inhibitors within prior 7 days
- Ischemic stroke within prior 3 months
- Intracranial arteriovenous malformation or aneurysm
- Known bleeding diathesis
- Chronic severe liver disease

Source: rhAPC labeling instructions.

than those who received rhAPC without heparin in a multicenter prospective randomized trial of 1,994 patients.(50) Patients who received rhAPC and heparin also had a lower ischemic stroke rate than those who received rhAPC without heparin although they had an increase in bleeding during the first 6 days.

> The patient was started on rhAPC 12 h after her percutaneous cholecystostomy. Although rhAPC increases bleeding risk, it has been demonstrated to improve survival in patients with a high risk of death and can be started 12 h after a surgical procedure if clinically indicated.

WHAT IS THE ROLE OF STEROIDS?
Steroid therapy for septic shock is a particularly contentious issue. A multicenter prospective randomized trial of 300 patients with septic shock demonstrated a mortality decrease from 63 to 53% in patients who did not respond to an ACTH stimulation test when treated with 1 week of hydrocortisone and fludrocortisone.(51) Patients who responded to the ACTH test had no benefit with steroid therapy. However, a larger follow-up multicenter prospective randomized trial of 499 patients with septic shock demonstrated no improvement in survival in either nonresponders or responders to ACTH stimulation (mortality 39.2% in patients treated with steroids, 36.2% in those treated with placebo) despite the fact that patients treated with hydrocortisone had hastened resolution of shock.(52) Patients treated with steroids had more episodes of superinfection, including new sepsis and septic shock. One possibility for why the results of these well-done, large-scale studies results are very different lies in a key difference in entry criteria consistent with the discrepancy in baseline mortality rates. In the former, patients were enrolled if they were in septic shock and despite adequate fluid resuscitation and pressor support, they had a systolic blood pressure less than 90 mmHg for greater than one hour. The latter study enrolled patients who were in septic shock despite adequate fluid resuscitation but there was no requirement about pressor responsiveness. As a result, the former study enrolled sicker patients which accounts for the marked differences in placebo mortality (63% vs. 36%) in the two studies. Expert opinion therefore suggests that hydrocortisone treatment be considered only in patients whose blood pressure is poorly responsive to both adequate fluid resuscitation and vasopressors.(4) Of note, high-dose steroids are not beneficial (and are possibly harmful) in septic shock, and if steroids are considered for fluid and pressor-resistant patients, doses >300 mg/day of hydrocortisone should not be used.(53, 54)

WHAT IS THE ROLE OF GLUCOSE CONTROL?
While severe hyperglycemia is detrimental in critically ill patients, the optimal blood glucose level is not known. A single center prospective randomized trial of 1,548 surgical (mostly cardiac) patients demonstrated a nearly two-fold decrease in mortality in patients who had tight blood glucose control with sugars in

the 80–110 mg/dl range compared to those with a goal range of 180–200 mg/dl.(55) A follow-up prospective randomized study at the same institution in 1,200 medical patients demonstrated a decrease in morbidity in patients treated with tight glucose control (days on the ventilator, acute renal injury, days in the ICU) but did not demonstrate a difference in mortality.(56) While most studies on glucose control look at all critically ill patients, a subsequent multicenter prospective randomized trial in 488 patients examined the effects of tight glucose control specifically in patients with severe sepsis or septic shock.(34) This study was stopped early for safety reasons. While 28-day mortality was similar in both groups, patients randomized to tight glucose control (80–110 mg/dl) had higher levels of hypoglycemia compared to those randomized to conventional therapy (180–200 mg/dl). Specifically, 17% of patients in the tight glucose control group had blood glucose levels < 40 mg/dl compared to 4.1% in the conventional group. In addition, the rate of serious adverse events was more than two-fold higher in those randomized to tight glucose control. Another multicenter prospective randomized trial in 1,101 surgical and medical ICU patients (not specifically septic patients) was also stopped early due to increased hypoglycemia in patients randomized to tight glucose control without any mortality benefit detected.(57) In contrast, a before/after study of 1,600 patients showed a 29% relative decrease in mortality with a relative reduction of 45% in a subgroup analysis of septic patients.(58) Other observational trials have also demonstrated decreased mortality in patients with lower glucoses, although the mean blood glucose necessary to achieve this benefit varies between studies.(59, 60) Based upon these widely varying results, expert consensus has recommended that patients should be placed on a validated insulin protocol with a glucose goal of < 150 mg/dl.(4) This protocol should include both a glucose calorie source and hourly monitoring of glucose levels until levels stabilize at which time monitoring can be reduced to every four hours.

WHAT IS THE ROLE OF BLOOD TRANSFUSIONS?
During initial resuscitation in septic shock, patients should be transfused to a hemoglobin > 10 mg/dl (hematocrit > 30%) if their $ScVO_2$ is < 70%. However, after initial resuscitation, the threshold to transfuse blood changes, and patients should not be transfused to keep their hemoglobin above 10 mg/dl unless there are specific clinical indications such as acute hemorrhage or active myocardial ischemia. Rather, blood should be transfused to keep hemoglobin levels > 7 g/dl. Although this has not been specifically studied in sepsis, these recommendations are based upon a multicenter, prospective, randomized trial of 838 critically ill patients in which mortality was generally unaffected by maintaining hemoglobin levels at 10–12 g/dL compared to 7–9 g/dL.(61) However, mortality rates were *lower* in patients with hemoglobins of 7–9 g/dl in patients who were less than 55 years old and in those who had APACHE II scores ≤ 20. A recent single-center retrospective study also demonstrates that the age of blood transfused affects outcomes.(62) Greater than 6,000 patients who underwent cardiac surgery were stratified into whether they received blood greater or less than 14 days old. Patients who received older blood had increased mortality (2.8% vs. 1.7%) and increased rates of sepsis (4.0% vs. 2.8%).

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43 Catheter-related infections
Spiros G Frangos and Heidi L Frankel

A 52-year-old man sustained a single gunshot wound to the abdomen and was brought to the emergency department in hemorrhagic shock with a blood pressure of 80/45 and pulse of 130. He was intubated for airway control secondary to combativeness, and a large-bore antecubital intravenous catheter was placed. There was difficulty establishing a second peripheral line, so a right femoral vein cordis was placed. Crystalloid and packed red cells were aggressively infused as he was transported to the operating room, where a shattered spleen was removed, multiple small bowel perforations were repaired, and a left hemicolectomy was performed. The patient was transferred to the surgical ICU (SICU). Using maximal barrier precautions (MBP) with a chlorhexidine site preparation, a cordis/pulmonary artery (PA) catheter was placed in the left internal jugular vein. The peripheral intravenous catheter and femoral cordis were removed. The patient was aggressively resuscitated over the next 24 h but was unable to be extubated secondary to acute respiratory distress syndrome. On the fifth postoperative day, he developed a fever of 103.5 °F, and blood cultures were sent to the laboratory; the PA catheter and cordis were changed over a wire to a triple lumen catheter. The PA catheter tip grew 35 colony-forming units of coagulase-negative staphylococci (CNS), and soon thereafter the lab confirmed positive CNS blood cultures. The sensitivities of the two organisms were identical. The triple lumen catheter (TLC) was removed, and, using MBP, an antibiotic-coated TLC was inserted in the right subclavian vein for parenteral nutrition. Antibiotics were also started. On postoperative day (POD) 7, a swollen right leg led to a deep venous thrombosis diagnosis, and heparin anticoagulation was initiated. The patient was successfully extubated on POD 10 and discharged from the hospital a week later on coumadin therapy.

CATHETER-RELATED INFECTIONS: GENERAL OVERVIEW

Demographics and Epidemiology of Catheter-Related Infections

Intravascular (IV) catheters are a mandatory adjunct to patient care in the intensive care unit (ICU) setting. The median rate of central line-associated bloodstream infections (BSI) ranges from 1.8 to 5.2 per 1,000 catheter-days in ICUs.(1, 2) The data imply that 80,000 central venous catheter-associated BSIs occur annually in United States (U.S.) ICUs.(3)

What Is the Morbidity, Mortality, and Cost of Catheter-Related BSI?

The attributable mortality from nosocomial BSI is high in critically ill patients (4), although, upon adjusting for preinfection severity of illness, this association may be lost.(5) Nonetheless, the high morbidity, the increased length of stay (LOS) within the ICU and hospital, and the associated increased costs are not in doubt, although there is some difficulty in deriving these numbers. Nosocomial BSIs result in a 5-day excess stay within ICUs and result in at least $16,000 of excess costs per episode.(6) When they occur in critically ill ICU patients, catheter-related (CR)BSIs are associated with an increase of $71,000 in ICU cost and a 20-day increase in ICU LOS.(7) The annual cost of caring for patients with central venous catheter (CVC)-associated BSIs may approximate half a billion dollars annually.(8)

Catheter Colonization: How Is This Term Defined? What's the Treatment?

As defined by the Center for Disease Control (CDC), catheter colonization is diagnosed if a positive culture of a catheter segment (15 or greater colony-forming units [cfu] if by semiquantitative culture or 1,000 or greater cfu if by quantitative culture) without clinical evidence of infection.(9) The semiquantitative technique, as described by Maki et al. (10), involves rolling a catheter segment back and forth across the surface of a blood–agar plate. It distinguishes infection (greater than 15 colonies) from low-density colonization or contamination. The quantitative technique involves placing the catheter segment in broth and sonicating it for 1 minute.(11) The broth is then vortexed, diluted, and surface-plated on soy agar. This method displaces intraluminal pathogens and increases the number of organisms that can be quantitated, as compared with the semiquantitative technique.(11) Treatment of catheter colonization is catheter removal; antibiotics are generally not indicated unless the diagnosis of a BSI cannot be ruled out (e.g., if blood cultures were not drawn).

Catheter-Related Blood Stream Infection: How Is This Term Defined? What's the Treatment?

As defined by the CDC, a catheter-related blood stream infection (CR-BSI) occurs when the same organism is cultured from a catheter segment (semiquantitative or quantitative) and from peripheral blood in a patient with a clinical infection but without another obvious source.(9) Peripheral blood cultures should be drawn prior to initiation of antibiotics. If a CR-BSI is suspected, the catheter should be removed and not changed over a guidewire. If a patient has an appropriate response to catheter removal, antibiotic treatment of a CR-BSI may be limited to 7 days. In general, antibiotic coverage should be individualized to the patient's overall clinical condition and to the virulence of the isolated organism. For example, methicillin-resistant *Staphylococcus aureus* CR-BSIs should be treated for up

Table 43.1 Common Pathogens Noted From ICU* BSI (January 1992–May1999).

Coagulase Negative *Staphylococcus*	37.3%
Enterococcus species	13.5%
Staphylococcus aureus	12.6%
Candida albicans	5%
Enterobacter species	4.9%
Pseudomonas aeruginosa	3.8%
Klebsiella pneumoniae	3.4%
Escherichia coli	2.3%
Other	17.2%

*hospitals performing either ICU or hospital wide surveillance components (NNIS System report: data summary from January 1990–May 1999, issued June 1999. Am J Infect Control 1999; 27: 520–32).

to 4–6 weeks. Likewise, immunocompromised patients may require a longer course, even with seemingly less virulent organisms. In general, empiric therapy usually involves vancomycin, since a number of the *Staphylococcus* species are methicillin resistant. Linezolid is a newer bacteriostatic agent that is indicated for the treatment of nosocomial infections involving Gram-positive organisms, including methicillin-resistant *Staphylococcus*. Patients in whom Gram-negative organisms are suspected may require an additional agent.

The case patient had a CR-BSI, as confirmed by identical catheter segment and peripheral blood cultures. The TLC (wire changed from a PA catheter) was appropriately discontinued, and antibiotics were initiated.

What Are the Common Pathogens Involved in CR-BSI?
CNS are the organisms that account for the majority (37.3%) of ICU BSIs.(12) (Table 43.1) *Enterococcus* species (13.5%) and *S. aureus* (12.6%) are the next most common. Gram-negative rods account for approximately 14% of BSIs with *Enterobacter* species predominating. The most common yeast isolate is *Candida albicans* (5%).

Over the last few years, there have been notable changes in the susceptibilities of these organisms to antibiotics. Vancomycin resistance amongst *Enterococcus* species and methicillin resistance amongst *S. aureus* species were noted to increase 47% and 43%, respectively, over a 5-year period in the late 1990s.(12)

CNS was the responsible pathogen, as it is in a third of all CR-BSIs.

By What Means Do Bacteria Infect Catheters?
Migration of skin organisms onto the subcutaneous (SQ) and then IV extraluminal portions of catheters is a common mechanism for catheter colonization and CR-BSIs, especially common in those central venous catheters that have been in place for 10 days (Figure 43.1).(13, 14) Likewise, hub colonization is a primary source of CR sepsis.(15) It usually results from frequent manipulation with eventual colonization of the internal luminal surface of the hub. Intraluminal migration to involve the body and tip of the catheter leads to sepsis. This mechanism appears to be an especially evident route with long-term (averaging 3 weeks) catheter use.(15) Less-frequent routes include hematogenous seeding of catheter tips and infusion of contaminated infusate. The latter route occurs only rarely, since current preparations of nutritional solutions have maintained high standards.

Staphylococcus epidermidis adhere to catheters and produce a matrix of extracellular polysaccharide (also known as slime), which contributes to their virulence. Slime interferes with the function of the cellular immune system by acting as a protective shield and reducing the effects on the lymphoproliferative response of mononuclear cells. (16) It also impedes the antimicrobial effect of certain antibiotics by inactivating them.(17)
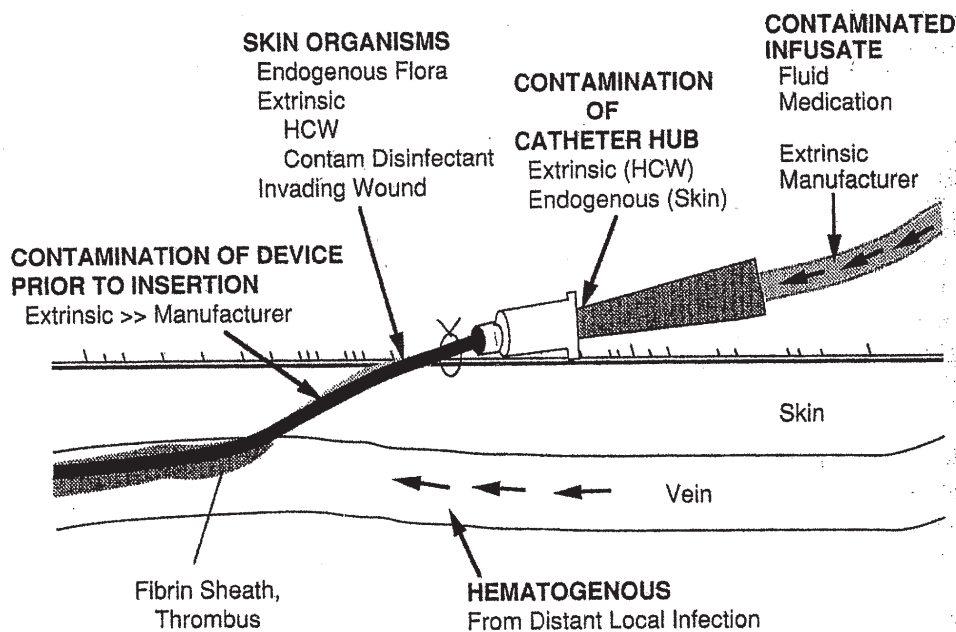
Figure 43.1 Mechanisms for acquiring catheter-related bloodstream infections.

PERIPHERAL LINES

What's the Data on Peripheral Venous Catheters? How Often Should They Be Replaced?

A dedicated IV therapy team significantly reduces both local and bacteremic complications of peripheral IV (PIV) catheters.(18) A large randomized controlled trial (RCT) comparing four dressing change regimens for PIV catheters revealed that either sterile gauze or a transparent dressing can be used without an increase in infection rates, and that PIV catheter dressings can be left until the catheters are removed.(19) The most important factor in reducing the occurrence of complications from PIVs appears to be timely replacement.(18) Current literature suggests that PIVs may be left in place up to 96 h without an increased risk of phlebitis.(20)

When Should Trauma Lines Be Removed?

Serious infections are usually associated with central, and not peripheral, IV catheters. Nonetheless, there are instances, as in trauma, when aseptic technique is poorly applied. For this reason, these catheters should be removed as soon as possible and within 24–48 h in all instances, despite the lack of high-quality evidence.

> The large-bore antecubital IV catheter placed in the trauma bay was appropriately removed soon after arrival to the SICU.

INSERTION SITE AND ANTISEPTIC TECHNIQUE

Which Is the Optimal Site for Central Venous Catheterization?

There is an increased risk of infection associated with the jugular (21) and femoral (22) approaches versus subclavian vein catheterization. It is possible that the jugular site has increased contamination from oropharyngeal secretions or that dressings adhere less well to the neck. Likewise, the groin area has an increased density of local skin flora, which makes femoral catheterization particularly susceptible to infections.

The femoral vein should be used for emergency venous access only. In addition to the infection risk, there is a significant increased rate (up to sixfold (23)) of ileofemoral deep venous thrombosis (DVT) with femoral vein catheterization.(24–26)

In general, the subclavian site is preferred, followed by the jugular site. Mechanical complications of jugular and subclavian lines include pneumothorax, hemothorax, carotid or subclavian artery injury, and misplaced catheter tip. The choice of an insertion site should, however, be individualized; the infection risk of catheter placement at a particular site should be balanced against the risk for a mechanical complication, including pneumothorax or central venous stenosis.(3)

> The femoral cordis was emergently placed for resuscitative purposes. Due to its urgent nature, this catheter was likely not placed using appropriate sterile technique. It was appropriately relocated soon thereafter to eliminate the possibility of catheter infection and attempt to prevent femoral thrombosis. The latter however resulted nonetheless.

> The internal jugular site was used to place the PA catheter. The evidence suggests an increased infection rate at this site, as opposed to the subclavian vein. The antibiotic-coated TLC was appropriately placed in the subclavian vein.

Are Maximal Barrier Precautions Necessary?

There is no question that prevention is the best means to avoid CR infections, and this begins with the education of health care workers in catheter insertion and maintenance. A multiapproach strategy for the prevention of CVC colonization and infection, targeted at catheter insertion and maintenance, decreases rates of vascular access infections.(27) This begins with catheter insertion and includes the preparation and collection of relevant materials to prevent procedural disruption, skin prep and antisepsis, maximal barrier precautions (MSBP), and insertion technique. Standardization of infection control practices, including the use of full-size sterile drapes, through a course on infection-control practices is a cost-effective way to reduce the rate of catheter-related infections.(28) One multifaceted system's intervention nearly eliminated CR-BSIs within a SICU.(29) A collaborative cohort study performed in Michigan State ICUs using evidence-based interventions to reduce the incidence of CR-BSIs resulted in an impressive reduction (up to 66%) in infection rates that was sustained throughout an 18-month period.(30) The use of Six Sigma corporate performance-improvement methodology has also been shown to successfully reduce CR-BSIs in a substantial and sustained manner within an ICU after more traditional strategies had failed.(31)

The value of hand hygiene in reducing infection transmission has been shown.(32) Good hand hygiene is a prerequisite for MSBPs, which include cap and mask, sterile gown and gloves, and large sterile drapes. MSBPs are a cost-effective method for reducing the risk of CVC-related infections; furthermore, the technique is consistent with the practice of universal precautions.(33)

> Maximal barrier precautions were appropriately used when central catheters were electively placed.

What Is the Optimal Site Preparatory Solution? Does It Matter?

A prospective, randomized trial compared three antiseptics: 10% povidone-iodine, 70% alcohol, or 2% aqueous chlorhexidine for disinfection of SICU central venous and arterial catheters at insertion (and subsequent every other day site care).(34) The lowest incidence of CR infection (2.3 per 200 catheters) was in the chlorhexidine arm versus 7.1 and 9.3 per 100 catheters for alcohol and povidone-iodine, respectively (p=0.02). The proper use of any antiseptic prior to vascular device insertion, however, requires that the solution be allowed to air-dry prior to any attempts at venous access.(3)

> *Chlorehexidine was used to prep the site.*

CATHETER SITE CARE

Is Catheter-Related Nursing Care Important?
How Often Should the Dressing Be Changed?

Catheter-related nursing care, including routine dressing changes and general handling, is a very important component of CR-infection prevention. Nursing staff reductions may contribute to increases in SICU CR-BSIs by making adequate catheter care difficult.(35) Simple techniques such as cleaning the injection port with an alcohol swab prior to instrumentation are an important component of catheter infection control.

Antibiotic Ointment? Gauze and Tape?
Transparent Membrane? Does It Matter?

The routine application of topical povidone-iodine ointment to hemodialysis catheter exit sites reduces the infection rate of subclavian catheters and is a cost-effective prophylactic method.(36) The application of mupirocin ointment after standard skin prep significantly reduces the colonization of central venous cannulae in cardiothoracic patients.(37) Mupirocin ointment applied to the insertion site of hemodialysis catheters was studied in end-stage renal disease patients and found to significantly reduce the risk of *S. aureus* catheter colonization, exit site infection, and bacteremia.(38) Resistance to topical antibiotics, however, limits the effectiveness of these treatments. Therefore, except for dialysis catheters, the application of topical antibiotic ointment to insertion sites is not recommended.(3)

Transparent dressings have a number of advantages over standard gauze dressings. They reliably secure the catheter, permit continuous inspection of the skin entrance site, and save personnel time.(3) A meta-analysis (39) of all studies published in the English literature investigated infection risks associated with transparent, compared with gauze, dressings for use on central, as well as peripheral, venous catheters. An increased risk of catheter-tip colonization/infection was associated with the use of transparent dressings, but the rates of CR-sepsis and bacteremia were equivalent in the two groups. At this point in time, no strong evidence exists to mandate the use of either; therefore, sterile gauze with tape or a sterile transparent dressing may be used.

SPECIAL CATHETERS

Do Additional Lumens Place Patients with Central
Venous Catheters at a Higher Risk for Infection?

A meta-analysis was performed to determine the risk of catheter colonization and CR-BSI in single versus multilumen central venous catheters.(40) When studies with long-term, cuffed, tunneled, and antibiotic-coated catheters were excluded, 15 studies met inclusion criteria. Of these, there was substantial variation among studies. Multilumen catheters were slightly more prone to CR-BSI than single-lumen catheters, although catheter colonization rates were the same. When patient differences were taken into account, the infection risks were the same for both colonization and CR-BSI, leading the authors to conclude that the improved convenience of miltilumen catheters justifies their continued use.
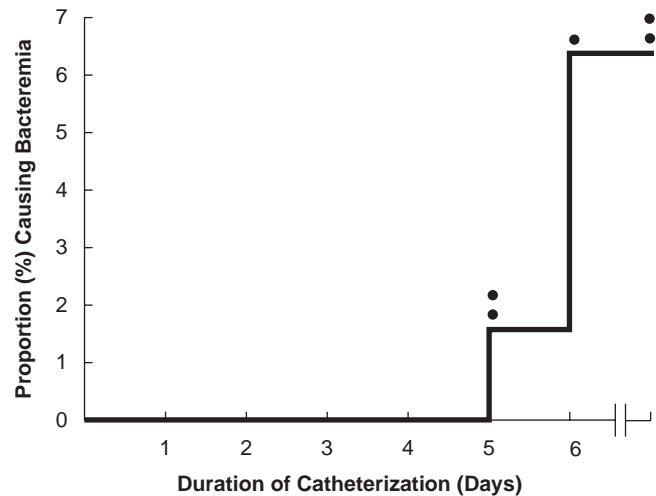
Figure 43.2 PA catheter-related infections increase preciptously after 5 days.

How Often Do Pulmonary Artery Catheters Get
Infected and How Often Should They Be Changed?

One prospective study revealed that PA catheter-related septicemia occurred at a rate of 2% before 7 days and 16% after 7 days of catheter placement, leading the authors to conclude that PA catheters should be changed every 4–7 days.(41) The authors of a prospective, randomized trial of 442 patients with PA catheters concluded that the risk of a PA catheter-related BSI should be exceedingly low if the duration of catheterization is limited to 4 days (Figure 43.2).(42) If right-heart catheterization continues to be necessary, the appropriate time to change these catheters appears to be between 4 and 7 days.

> The PA catheter infection occurred on day 5. A PA catheter was no longer mandatory for managing this patient (since a TLC was placed after the infected PA catheter was removed). This implies that the PA catheter could have been removed sooner and not allowed to reach the 5-day mark.

Are Antiseptic-Impregnated Central Venous
Catheters Effective in Reducing CR-BSI Infection?
When Should Antiseptic-Impregnated Central Venous
Catheters Be Used?

Antiseptic-impregnated CVCs have been proven to reduce CR-infection rates. Triple-lumen, noncuffed CVCs that have been impregnated with minocycline and rifampin (43) or chlorhexidine and silver sulfadiazine (44, 45) reduce the risk of catheter colonization and CR-BSI. Clinical application of these findings will help reduce the costs associated with CR-BSIs, despite the fact that these catheters are more expensive than standard TLCs.(46) The two types of antiseptic-catheters have been compared against one another. The minocycline/rifampin-impregnated catheters were 1/3 as likely to be colonized (7.9% vs. 22.8%, p<0.001) and CR-BSIs were 1/12 as likely (0.3% vs. 3.4%, p<0.002) as those catheters impregnated with chlorhexidine/silver sulfadiazine.(47) It is possible, however, that this difference in efficacy may be attributed

to the fact that only the external surface of the chlorhexidine/silver sulfadiazine catheters was impregnated with antimicrobial agents, as opposed to both the external and internal surfaces in the minocycline/rifampin group.(47) Second-generation chlorhexidine/silver sulfadiazine catheters, which have both surfaces coated and are now available, will need to be studied further to help uncover the efficacy discrepancy.(3)

Resistance data from the utilization of coated catheters is being acquired, and definitive conclusions cannot be drawn. The amount of time to keep these catheters in place has not been fully elucidated either, though 14 days may be an appropriate minimum. These special catheters should be used when there is a need to enhance prevention of CR infection beyond that provided by standard infection control techniques. They should be used in patients who have a greater than 5-day need for central venous access. Of course, costs and concern for acquired resistance need to be kept in mind.(3)

> Since the patient had already been diagnosed with a CR-BSI, had continued need for central access, and was expected to remain intubated and in an ICU setting for an additional period of time, an antibiotic-coated catheter in this setting is beneficial.

What's the Data on Tunneled Versus Nontunneled Catheters?

The tunneling of short-term venous catheters appears to decrease the rate of CVC-related infections at the internal jugular site.(48) However, subcutaneous tunneling of subclavian catheters has not been shown to reduce the risk of infection.(49) As a routine practice technique, tunneling cannot be currently recommended until issues of performer experience and patient safety are further evaluated and until efficacy and cost comparisons with other simpler infection-reducing methods are conducted.(49)

ROLE FOR GUIDEWIRE CHANGES? ROLE FOR PROPHYLACTIC ANTIBIOTICS?

Should Central Venous Catheters Be Routinely Replaced or Changed over Guidewires?

Scheduled routine CVC changes should not be performed.(50) A well-conducted RCT of routine replacement of central venous or PA catheters every 72 h found that infections were not reduced and that guidewire exchange increased the risk of BSIs.(51) A systematic review of the literature (reviewing 12 RCTs) revealed that guidewire exchange of CVCs, as compared with new site replacement, is associated with a trend toward a greater risk of CR infection.(52) Guidewire replacement of catheters should be used to replace malfunctioning catheters or to exchange a PA catheter for a TLC.(3)

Of course, any CVC that is not essential to the care of a patient should be removed at the earliest possible time. There is no role for routinely culturing CVC tips.(4) Purulence at the insertion site, with or without systemic symptoms, mandates catheter removal.

> A slightly higher clinical suspicion for CR-BSI may have led to an alternate, potentially more appropriate, management strategy—removing the PA catheter and cordis, starting empiric antibiotics, and finding central access at a new site (i.e., subclavian vein) prior to culture results.

Is There a Role for Prophylactic Antibiotics or the Antibiotic Lock Technique?

There is no role for preinsertion systemic antibiotic prophylaxis to reduce the incidence of CR-BSI.(53, 54) CR infections are not reduced, and the selection of resistant organisms cannot be disregarded.

A number of well-executed studies have shown that the antibiotic-lock technique (allowing antibiotic solution to dwell within the catheter lumen) prevents catheter colonization and bacteremia in certain patients with malignancies who have both tunneled (55) and nontunneled (56) catheters. The data cannot be extrapolated to the population at large; furthermore, fear of selecting for resistant organisms has curbed enthusiasm of this technique. The antibiotic lock technique should not be routinely used.(3)

Table 43.2 summarizes the aforementioned evidence-based data along with the level of evidence based on the Strength of Recommendation Taxonomy (SORT) as utilized in GRADE methodology.(57) Adherence to these recommendations should allow ICUs to decrease their rates of catheter-related infections.

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44 Special Populations in Trauma
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A local church bus crashes on its way to a rally. On board were Mr. A (a 300-lb deacon), Mrs. B (the 80-year-old organist), Mrs. C (the 8—month-pregnant choir director), and Mr. D (the pastor's 11-year-old son). Prehospital personnel find all four awake and responsive to commands. After clinical assessment, intravenous access is established in all patients and isotonic fluids are provided. All four patients are transferred to the nearest trauma center, where they are found on primary survey to have intact airway with adequate spontaneous ventilation, no evidence of external hemorrhage, and Glasgow Coma Scores of 15. Vital signs are within normal limits. All four complain of right upper quadrant pain and pelvic pain. Secondary survey is notable in all patients for abdominal tenderness in the right upper quadrant without signs of peritonitis. Additionally, Mrs. C is noted to have a gravid uterus with the fundus palpable well above the umbilicus. Severe pain and pelvic instability are noted on lateral compression of the pelvis. No other obvious deformities are identified. Routine trauma laboratory tests have been sent during the secondary survey. Radiographic technologists await instructions for imaging.

The choice of imaging for an injured patient is a crucial decision that requires careful consideration. Although details of trauma imaging are provided elsewhere in this book, it is worthwhile to review the basic concepts. The advanced trauma life support (ATLS) paradigm suggests that immediate chest and pelvic radiographs be performed as part of the primary survey. Following the initial plain film assessment, further evaluation of the hemodynamically stable patient with suspicion for blunt abdominal injury is needed. The focused abdominal sonography in trauma (FAST) exam is a rapid bedside test that allows assessment of intraperitoneal and pericardial fluid. At many centers, FAST has been incorporated into the secondary survey as a standard procedure, although a recent Cochrane review concluded that there was insufficient evidence to support the use of ultrasound in abdominal trauma, based on the limited number of randomized studies performed.(1) Although the FAST exam is highly specific for intraabdominal injury, care must be taken to remember the low sensitivity of FAST.(2) FAST is excellent for the detection of hemoperitoneum, but clinically significant hollow organ injuries as well as solid organ injuries without free hemorrhage may be missed on ultrasound.(3, 4, 5) Because of this finding, another diagnostic modality (usually computed tomography [CT]) is indicated in the case of a negative FAST exam in a stable patient.(6)

Abdominal CT with intravenous contrast is an excellent modality for evaluation of intraabdominal injuries in the blunt trauma population (discussed more thoroughly elsewhere in this book).(7, 8) Recent advances in multidetector CT have increased the speed and quality of imaging.(9) One concern in the use of CT is the increased risk of nephropathy from the use of intravenous contrast agents. Although this concern should not delay a scan needed for the diagnosis of potentially life-threatening injuries, the potential for this complication should be remembered by the clinical care team. The risk–benefit ratio (as well as the feasibility) postscan of hydration and *N*-acetylcysteine should be considered.(10—12)

Obese: Body habitus may contribute to a technically challenging FAST exam; however, there are no specific contraindications to use in this population. Many CT scanners have an upper weight limit, which may prevent use of CT scan in the superobese.

Geriatric: No special issues surround the use of the FAST exam in the geriatric population beyond the concerns inherent to the FAST exam itself. When considering CT imaging, it is important to note that normal aging leads to a progressive loss of nephrons in the kidney and therefore a decrease in glomerular filtration rate.(13) Because of this factor and the overall increased incidence of chronic renal insufficiency in the geriatric population, renal protective strategies for IV contrast exposure should be seriously considered as mentioned above.

Pediatric: FAST has been well described in the pediatric population, but its overall effectiveness is unclear.(14–17) A meta-analysis of FAST in pediatric trauma concluded that FAST had modest 50% sensitivity for the detection of intraabdominal injury, but 97% specificity.(18) The authors recommend that a negative exam in the setting of a moderately high suspicion of injury should lead to a subsequent CT scan to rule out intraabdominal injury. CT for blunt abdominal injury is well accepted in pediatric practice.(19)

Pregnancy: FAST has not been prospectively examined in the pregnant population. Ultrasound is not believed to cause harm to the fetus and is widely used during pregnancy. Anatomic distortion has been suggested as a potential pitfall of the FAST exam in the third trimester based on anecdotal experience.(20) However, in a retrospective review of 208 pregnant trauma patients (59 in the third trimester), 83% sensitivity and 98–100% specificity for intraabdominal injuries was noted using FAST. (21) The authors concluded that the performance of FAST in pregnant patients paralleled its performance in nonpregnant patients. Bedside, ultrasound has also been described in a case report as a tool to detect fetal heart tones during evaluation for an emergency Caesarian section delivery when the mother is in extremis.(22)

During pregnancy, the major imaging concern is potential radiation exposure. Fetal radiation exposure totaling less than 5 rads is not believed to have an adverse effect.(23) An abdominopelvic CT scan is estimated to produce approximately 3.5 rads of exposure. As the best way to care for the fetus is to care for the mother, diagnostic tests should be performed as needed

to ensure the mother's well-being.(24) If a CT scan is deemed clinically necessary, then it should be obtained. The abdomen should be shielded from radiation for all nonabdominal studies. Consultation with a radiologist may be indicated to evaluate the total radiation dose, resulting from multiple procedures in the severely injured patient.(24)

> Cervical spine, chest, and pelvic radiographs were performed according to ATLS protocol. Cervical spine and chest films for all patients were unremarkable. Pelvic radiographs for all four patients were notable for the presence of LC1 grade pelvic fractures. A FAST scan was performed as part of the secondary survey and demonstrated positive-free fluid in the right pericolic gutter. As vital signs had remained stable, the patients were taken for abdominopelvic CT scan with intravenous contrast. This revealed the previously identified LC1 pelvic fracture and additionally demonstrated a grade 4 liver laceration without active contrast blush. No other intraabdominal injuries were identified.

Nonoperative management (NOM) of liver injuries is feasible in the setting of a stable patient with any grade of liver injury (25–27) and is explored more thoroughly elsewhere in this book. Eligible patients must be hemodynamically stable (systolic blood pressure > 90 mmHg and heart rate < 100 bpm), lack radiologic evidence of another injury requiring operative intervention, and have no peritoneal signs on physical exam.(28) The presence of a contrast blush on abdominal CT should also direct the clinician toward operation or angioembolization due to a high rate of failure in the presence of high-volume active hemorrhage. (29) Patients with liver injury treated by NOM should be carefully monitored for deterioration in their clinical condition. Development of hemodynamic instability is considered a failure, at which point operative intervention or angioembolization may be needed. For the patients in this scenario, their high-grade liver injuries may increase the likelihood of failure of NOM but is not a contraindication.(30)

The degree of monitoring required by patients undergoing NOM of liver injury depends on the patient's clinical condition. At a minimum, the patients in this scenario should be placed in a unit that can provide continuous monitoring. The combination of pelvic fracture and liver injury require careful supervision with continuous telemetry and pulse oximetry. A central venous line may be required for more detailed assessment of the central venous filling pressures and venous oxygen saturations to guide resuscitation. Pulmonary artery catheters (PACs) are rarely indicated in this setting; they may be considered in the setting of underlying cardiac comorbidities that complicate resuscitation. The development of hemodynamic instability in these patients should trigger reevaluation for surgical intervention.

Obese: There are no specific contraindications to nonoperative management in the obese population. Hemodynamic monitoring recommendations are unchanged.

Geriatric: Although historically NOM has been associated with a greater risk of failure in the elderly population, advanced age alone should not be considered a contraindication to NOM. (31) Careful patient selection based on degree of injury and hemodynamic status should guide the management decision.

A retrospective study of geriatric trauma patients found that early invasive hemodynamic monitoring with a PAC and intervention to improve cardiac output was associated with improved survival.(32) The Eastern Association for the Surgery of Trauma practice guidelines group therefore recommends use of a PAC in elderly patients who have a significant mechanism of injury, physiologic compromise, or chronic renal or cardiovascular disease (33), although level 1 evidence is not available. There are no generally accepted targets for resuscitation in this population, although a cardiac index (CI) of 4.0 L/min/m^2 with adequate serum markers of resuscitation (correction of lactate and base deficit) are commonly accepted.(34)

Pediatric: NOM for hepatic injuries in pediatric patients is widely practiced. As with adults, hemodynamic instability is the primary contraindication to NOM and development of instability should be regarded as a failure (including need for blood transfusion greater than 25 mL/kg in the first 2 h after admission).(35) As in adults, injury grade is not a contraindication to NOM in the pediatric population (36), although patients with grades 3 and 4 injuries are at higher risk of hepatic complications such as biloma.(37)

Pregnancy: There is no specific data regarding NOM of hepatic injuries in pregnancy. A high index of suspicion for failure should be maintained if NOM is contemplated in a pregnant patient. Indicators of fetal instability should be considered signs of failure, and intervention should be expeditiously implemented if any signs of instability are noted.

Hemodynamic monitoring for the mother should follow the guidelines described above. In women over 20 weeks pregnant, continuous cardiotocographic monitoring should be initiated as soon as possible after completion of the primary and secondary survey and continued for at least 6 h.(24) Monitoring should be continued indefinitely if uterine contractions are occurring. Patients should also be monitored during invasive procedures or radiologic tests.(38) Fetal monitoring should be interpreted by qualified obstetrical personnel.

> Several days after injury, all four patients develop progressive respiratory distress and require endotracheal intubation. Mechanical ventilation is initiated.

Trauma patients are at high risk for the development of acute lung injury (ALI) and its more severe form – the acute respiratory distress syndrome (ARDS, Table 44.1.). Overall, the incidence of ARDS in critically injured trauma patients appears to be declining over time. Martin reported a decrease in the diagnosis of ARDS (early or late form) in critically injured trauma patients from 23% in 2000 to 9% in 2004.(39) Plurad and colleagues found that the occurrence of late ARDS in critically injured trauma patients requiring mechanical ventilation decreased from 14.8% in 2000 to 3.9% in 2005.(40) The authors ascribed this finding to implementation of a more restrictive blood transfusion strategy and improvements in mechanical ventilation. A prospective study

Table 44.1 Diagnostic Criteria for ALI and ARDS.(114)

ARDS
Acute onset
PaO_2 / FiO_2 ratio less than 200
Bilateral infiltrates on chest radiograph
No evidence of left atrial hypertension (pulmonary capillary wedge pressure < 18 mmHg, if measured)

ALI
Same as above, except PaO_2 / FiO_2 ratio less than 300

examining the number of units of red cells transfused in the first 24 h after admission found a significant positive association between increasing transfusions and the risk of subsequent ARDS even after controlling for severity of injury and demographic factors.(41)

The traditional definition of ARDS may not be as applicable to trauma patients as it is to other populations. Croce defined two forms of posttraumatic ARDS – an early form resulting from hemorrhagic shock and capillary leak and a late form related to multiorgan system failure (MOSF) and to pneumonia.(42) Mortality in these two groups was similar. Dicker and colleagues also identified an early and late subset of ARDS and suggested that the formal definition of ARDS was inadequate to fully describe the breadth of disease seen in the trauma population.(43) Analysis of trauma patients with ALI enrolled in two ARDSNet trials supports the theory that trauma patients are different than the general population. Trauma patients had significantly lower odds of death (odds ratio 0.44) than nontrauma patients even after controlling for differences in age and comorbidities.(44) Treggiani and colleagues found that neither ALI nor ARDS had any impact on mortality above and beyond the impact of the original injury in critically injured trauma patients once they adjusted for severity of injury and demographic factors.(45) In this cohort, the crude risk of mortality with ALI was 9% versus 16% for ARDS; patients without lung injury had a 3% mortality rate. Scalea found that the overall mortality for trauma patients with ARDS was 21.4%.(46)

Management of ARDS focuses on a low-stretch ventilation strategy to reduce volutrauma and barotrauma. Low tidal volume (6 mL/kg) decreases the peak inspiratory pressure and has been shown to positively affect mortality in patients with ALI and ARDS.(47) Positive-end expiratory pressure (PEEP) is applied as needed, but higher PEEP has not been shown to be beneficial.(48) A review of potential adjunctive measures such as prone positioning and nitric oxide is beyond the scope of this chapter (see Leaver(49) or Wheeler(50)).

Obese: Whether obesity impacts mortality from ARDS is unclear. A retrospective review of 1,488 patients with ALI found that overweight, obese, and severely obese BMI categories had a *decreased* risk of mortality from ALI (adjusted odds ratios 0.72, 0.67, 0.78 respectively).(51) However, a review of patients enrolled in three ARDSNet randomized controlled trials (RCTs) found no impact of obesity on mortality from ALI and no evidence that the effectiveness of the ARDSNet ventilation protocol was affected by obesity .(52) Further studies are needed to address this question.

Geriatric: The impact of age on the incidence of ARDS is uncertain. A registry study of 4,080 trauma patients at one center found that patients aged 60–69 years had a higher incidence of development of ARDS than younger patients when controlling for injury severity and demographics, but the risk decreased in older patients.(53) Age greater than 65 has been associated with increased mortality in both medical ICU and mixed medical–surgical ICU patients with ARDS.(54, 55)

Pediatric: Although the results from the ARDSNet trial have not been replicated in the pediatric population, low stretch ventilation as described above is the accepted strategy for management of pediatric ARDS.(56)

Pregnant: Pregnant patients have increased risk for aspiration due to decreased esophageal smooth muscle tone and increased gastric volume.(57) Aspiration may occur during intubation for respiratory distress, but it may also contribute to the development of pneumonia or ARDS. Pregnancy-specific causes of ARDS include preeclampsia and the HELLP syndrome (hemolysis, elevated liver function tests, and low platelets) as well as amniotic fluid embolism. Amniotic fluid embolism is associated with delivery and results from exposure of the maternal circulation to amniotic fluid. Chorioamnionitis (in the Prepartum period) and endometritis (in the postpartum period) may also contribute to the development of ARDS. ARDS during pregnancy is associated with 25–44% maternal mortality (58, 59); one series described evidence of fetal asphyxia in 30% of live-born deliveries to women with ARDS.(58)

Management of ARDS in the pregnant trauma patient is complicated by the physiologic changes that accompany pregnancy. Functional residual capacity is reduced in the pregnant patient, and a compensated respiratory alkalosis is normal during late pregnancy.(57) As a result, a normal $PaCO_2$ in late pregnancy is a warning sign of potential respiratory failure. For intubated patients, the ARDSNet protocol is used as described above; however, the oxygenation goal must be higher in the pregnant patient as compared to the nonpregnant patient, as a maternal $PaO_2 \geq 70$ mmHg (95% saturation) is necessary to ensure adequate fetal oxygenation. The carbon dioxide gradient between mother and fetus must be at least 10 mmHg to allow adequate elimination of CO_2; therefore, respiratory acidosis is poorly tolerated. Furthermore, the normal reduction in plasma oncotic pressure during pregnancy may contribute to pulmonary edema with normal or minimally elevated pulmonary artery pressure.(60) There is no data on prone positioning or inhaled nitric oxide in the pregnant population. Although elective delivery has been suggested during late pregnancy to improve ventilation, this is not supported by available evidence and is therefore not currently recommended.(61)

Over the ensuing hospitalization, all four patients develop septic shock.

Septic shock in the trauma patient can be a challenging diagnosis. The inflammation incited by severe trauma alone can lead to the development of the systemic inflammatory response syndrome (SIRS; Table 44.2), and as a result distinguishing between SIRS and sepsis (defined by the presence of infection) can be

Table 44.2 Definition of SIRS, Sepsis, and Septic Shock in Adults. (113)

SIRS
Temperature <36°C or >38°C
Heart rate > 90 bpm
Hyperventilation, defined as $PaCO_2$ < 32 mmHg or respiratory rate > 20
White blood cell count < 4,000 or > 12,000 cells/μm^2

Sepsis
SIRS + documented infection

Severe Sepsis
Sepsis + evidence of organ dysfunction (Marshall multiple organ dysfunction score, or sequential organ failure assessment criteria)

Septic Shock
Sepsis + persistent arterial hypotension despite adequate fluid resuscitation (mean arterial pressure < 60 or systolic blood pressure < 90)

challenging. Severe sepsis occurs when a septic patient develops organ dysfunction, and septic shock supervenes when arterial hypotension is noted despite adequate fluid resuscitation. Early diagnosis and treatment is essential in this population, as overall mortality in adult patients with septic shock is as high as 37%.(62)

The potential infectious sources in trauma patients are diverse. Missed hollow viscus injury or breakdown of surgical anastomoses can lead to intraabdominal sepsis. Open contaminated traumatic wounds can develop soft tissue infections. The high rate of invasive instrumentation, including urinary catheters, central venous lines, intracranial pressure monitors, and surgical drains provide multiple access routes for infection. Hematogenous spread of infection can lead to seeding of previously sterile hematomas or other body fluid collections. Evaluation of infection in the trauma patient should include cultures of accessible fluids from any sterile site. However, in the appropriate clinical setting, treatment of sepsis should not wait for culture results. Therapy should be initiated expeditiously to maximize patient outcome.

Treatment of septic shock involves optimization of hemodynamic parameters and rapid administration of appropriate antimicrobial therapy. In the seminal article by Rivers et al., early goal-directed therapy within 6 h of admission dramatically improved outcome in septic patients.(63) Current evidence-based guidelines for hemodynamic monitoring stem from these data. It is strongly recommended that a central venous line be placed for optimum monitoring of central venous pressure (CVP), with a goal of 8–12 mmHg and goal mixed venous saturation of 70%. Use of the PAC has fallen out of favor in recent years due to multiple studies that failed to find a beneficial impact of PACs in management. Antibiotic therapy should be started as soon as possible and subsequently be tailored to culture results.

Use of corticosteroids in septic shock has been a highly controversial issue since at least 1976, when Schumer described a significant reduction in mortality using high-dose corticosteroids in sepsis.(64) Subsequent studies did not confirm the benefit of high-dose steroids, and this treatment subsequently fell out of favor.(65–67) A renaissance in the use of steroids for sepsis began with published reports of a beneficial mortality effect from low-dose steroids (200–300 mg hydrocortisone/day).(68–70) Duration of vasopressor dependence was reduced with steroids,

shortening the duration of shock. These studies triggered the inclusion of low-dose steroids as a recommendation for patients who are poorly responsive to vasopressors in the Surviving Sepsis campaign in 2004.(71) Further impetus came with studies demonstrating a role of the adrenocorticotropic hormone (ACTH) stimulation test in identifying patients who were relatively adrenally insufficient.(72) However, recent studies have cast doubt on the use of low-dose steroids. The CORTICUS trial found no impact of low-dose corticosteroids in septic shock, regardless of response to the adrenal stimulation test.(73) Currently, there is insufficient evidence to support the routine use of low-dose corticosteroids in septic shock, and there is insufficient evidence to support or refute the use of the ACTH stimulation test in sepsis. Steroids may be helpful in the management of early septic shock with vasopressor dependence as steroids do appear to hasten the reversal of shock.(73)

Use of activated protein C (APC) in septic shock is another area of contention. The PROWESS trial found remarkable reduction in mortality following administration of APC (Xigris, Eli Lilly), especially in patients with an APACHE score equal to or greater than 25. This served as a springboard for a number of guidelines and articles extolling the virtues of APC in sepsis, such as the 2004 Surviving Sepsis Guidelines. However, there were a number of potential problems with the PROWESS study. First, the study protocol was changed partway through the study and the drug was reformulated from new cell lines. Data from the patients accrued after the change was significantly more supportive of the drug than data before the change. Furthermore, the cutpoint of APACHE score at least equal to 25 was found on an unplanned subgroup analysis. The ADDRESS study subsequently examined the use of APC in low-risk septic patients, defined by an APACHE score less than 25, and found no effect on mortality but an increase in hemorrhagic complications.(74) Meta-analysis of the available data suggests no clinical benefit from APC in either high-risk or low-risk patients combined with an increased risk of hemorrhagic complications.(75) In these patients who are at high risk for potential hemorrhage due to their traumatic injuries, we would not recommend the use of APC.

In the seminal article by van den Berghe, intensive insulin therapy to maintain blood glucose levels between 80 and 110 mg/dL significantly decreased mortality from MOSF with sepsis in a cohort of surgical patients enrolled on admission to the intensive care unit.(76) Based on these findings, there has been great interest in implementing tight glycemic control protocols for critically ill patients. Recent work has demonstrated that hyperglycemia is associated with poorer outcomes in trauma patients (77–84) and that hyperglycemia may have a greater impact on trauma patients than on other hospitalized patients.(85) However, subsequent work has not demonstrated as dramatic results as van den Berghe. A recent RCT of intensive insulin therapy in patients with severe sepsis or septic shock found an increased risk of severe hypoglycemic events in the tight glucose control arm and was terminated early due to safety concerns.(86) A recent quasi-experimental study demonstrated decreased morbidity and no increased incidence of hypoglycemia in the critically injured trauma population following institution of aggressive glycemic control; but paradoxically, a near doubling of mortality was also

found.(87) The true role of intensive insulin therapy in the septic trauma patient will remain uncertain until RCTs are completed in the trauma population. At this point, we would recommend cautious initiation of insulin therapy in septic trauma patients to maintain blood glucose < 110 mg/dL. Strict attention must be paid to avoid hypoglycemic episodes.

Obesity: The recommendations for care and sources of infection in the septic obese patient are unchanged from above. There is evidence to suggest that obese critically ill nontrauma patients have higher rates of sepsis (88) and higher overall mortality rates (88–91) than nonobese critically ill patients, but the specific impact of obesity on mortality from septic shock remains to be elucidated.

Geriatric: Geriatric trauma patients have higher rates of nosocomial infection than nongeriatric patients, and this is associated with increased morbidity and mortality.(92) Geriatric patients as a whole develop sepsis at higher rates and have higher resulting mortality, than younger patients.(62, 93, 94) This is likely due to a combination of an increased frequency of comorbid conditions as well as the gradual decline in immune system function that occurs with aging.(95, 96) Treatment of septic shock in geriatric patients follows the guidelines outlined above.

Pediatrics: Treatment of septic shock in pediatric patients parallels treatment in adult patients with a few specific exceptions. Blood pressure in the pediatric patient is a less reliable indicator of hypoperfusion in the adult since children have tremendous capacity to compensate for decreased cardiac output by peripheral vasoconstriction and tachycardia. Hemodynamic monitoring of the pediatric patient therefore focuses on clinical signs of poor perfusion such as urine output, capillary refill, heart rate, and mental status. Central venous access is indicated in cases of fluid-refractory shock requiring vasoactive agents, and a PAC may be placed when shock persists despite therapy targeted at maintaining superior vena cava oxygen saturation above 70% and at clinical parameters.(97) Dopamine is considered the initial vasopressor of choice in the pediatric sepsis population. Evidence supporting the use of vasopressin in children is limited to small retrospective reports that suggest a potential benefit in blood pressure and urine output.(98, 99) Pediatric patients in a low cardiac output state combined with high peripheral vascular resistance may benefit from milrinone or amrinone, which are rarely used in septic adults.

A large RCT of APC in 477 pediatric sepsis patients by the RESOLVE study group found no appreciable impact of APC on time to organ failure resolution and was terminated early due to futility.(100) Although the safety profile appeared acceptable in patients over 2 months of age, the increased risk of intracerebral hemorrhage in patients younger than 2 months (4 of 5 intracerebral bleeding events occurred in this group) led the authors to suggest avoiding enrolling this population in future studies. (101) The only other RCT in this arena was a phase 2 trial – the administration of protein C concentrate to pediatric patients with meningococcal sepsis. No excess hemorrhage events were observed in the treated population and as expected no difference in mortality was noted.(102) Because of the paucity of data supporting APC use in children and the high potential risk, the Surviving Sepsis Campaign guidelines therefore discourage the use of APC in pediatric sepsis.(103) There are no studies evaluating intensive insulin therapy in the nondiabetic critically ill pediatric population; although prevention of severe hyperglycemia seems advisable, strict caution should be used when administering intravenous insulin to the pediatric population, in order to avoid potentially deleterious hypoglycemic events. Overall mortality in septic pediatric patients (regardless of trauma) is approximately 10%, substantially better than the adult population.(104)

Pregnancy: One cause of sepsis unique to the pregnant patient is chorioamnionitis or infection of the fetal membranes. Chorioamnionitis conveys elevated risk of both maternal and fetal morbidity and mortality and requires immediate antibiotic therapy and delivery of the fetus.(105) Symptoms of this condition include fever, maternal and fetal tachycardia, uterine tenderness, and foul-smelling amniotic fluid. Unfortunately, in the severely injured pregnant population, there may be multiple coexisting causes of fever and tachycardia, and the patient may be unable to report uterine tenderness. Therefore, the diagnosis of chorioamnionitis may be challenging and should be made in close consultation with the obstetrical consultants. Amniocentesis may be needed to confirm the diagnosis.(106) Other potential pregnancy-related sources of infection include postpartum endometritis.

Only anecdotal evidence has been published on the treatment of sepsis in pregnancy. Early and aggressive antibiotic therapy and goal-directed resuscitation, as described above, are essential for the management of the pregnant patient.(106) There has been no prospective evaluation of CVP-driven therapy for sepsis in pregnancy, and it is important to note that hemodynamic parameters may be altered in the gravid woman. Dilutional anemia is normal as the plasma volume increases during pregnancy, and cardiac output increases to meet metabolic needs. Poor cardiac output in pregnant septic patients is associated with adverse outcomes. (107) The use of left-lateral tilt position can improve venous return to the heart and therefore improve hemodynamics. There is no contraindication to the use of vasopressor agents during pregnancy when clinically indicated.(106) Of note, the normal bicarbonate level in pregnancy is only 18–21 mEq/L.(60)

A recent case report has described the successful uncomplicated use of APC in an 18-week pregnant patient.(108) APC has also been hypothesized to be a potential treatment for preeclampsia, but this has not been formally evaluated.(109) Clinical judgment must balance the potential risk for increased hemorrhage with potential benefit of APC. Intensive insulin therapy has not been formally addressed in the pregnant patient and can be initiated according to the guidelines above. The utility of steroids in the pregnant septic patient is also unclear due to the lack of data in this population. Guinn and colleagues suggest empiric treatment with hydrocortisone due to alterations in cortisol metabolism during pregnancy (106), while Fernandez-Perez recommends avoidance of corticosteroids during pregnancy.(110) Treatment with dexamethasone for fetal lung maturity is indicated in cases of anticipated preterm labor (111), but this has no known effect on septic physiology.

In a case series of 18 nontrauma patients, maternal mortality from sepsis was 18% and fetal mortality (in > 24 week gestation pregnancies) was 29%.(107) It has been suggested that pregnant

women overall suffer a lower overall mortality rate from septic shock due to young age, few comorbid conditions, and predisposition for infection with highly susceptible organisms (112); however, this reflects community acquired infection and is therefore of questionable predictive value in the nosocomial setting.

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RADIOLOGIC EVALUATION

Obesity
No group-specific recommendations.

Geriatric
Consider prophylaxis for contrast nephropathy if computed tomography (CT) scan is chosen (2C).

Pediatric
Focused abdominal sonography in trauma and/or abdominal CT is appropriate for initial evaluation in the pediatric clinical setting (1B).

Pregnancy
Perform radiologic tests as needed to preserve the health of the mother (1C).

Use appropriate shielding of the uterus whenever possible (1C).

Consult with a radiologist if the estimated total exposure is > 5 rads (1C).

NONOPERATIVE MANAGEMENT OF LIVER INJURIES

Obese
No group-specific recommendations.

Geriatric
Advanced age is not a contraindication to nonoperative management (NOM) if appropriate patient selection is used (2C).

Pulmonary artery catheterization may provide benefit in geriatric patients with significant mechanism of injury, physiologic compromise, or chronic disease (2C).

Pediatric
No group-specific recommendations.

Pregnancy
Consider fetal distress an indicator of hemodynamic instability when assessing for failure of NOM (1C).

Use continuous cardiotocographic monitoring in patients > 20 weeks pregnant (1C).

Cardiotocographic monitoring should be interpreted by qualified obstetric personnel (1C).

RESPIRATORY FAILURE/ACUTE RESPIRATORY DISTRESS SYNDROME

Obese
No group-specific recommendations.

Geriatric
No group-specific recommendations.

Pediatric
No group-specific recommendations.

Pregnancy
Oxygenation goals must be higher for the pregnant patient than the nonpregnant patient; maternal $PaO_2 \geq 70\,mmHg$ (95% saturation) is necessary for adequate fetal oxygenation (1C).

Elective delivery to improve ventilation is not recommended (1C).

SEPTIC SHOCK

Obesity
No group-specific recommendations.

Geriatric
No group-specific recommendations.

Pediatric
Use of activated protein C in sepsis is discouraged in pediatric patients (1B).

There is no evidence regarding tight glycemic control in septic pediatric patients.

Pregnancy
Consider pregnancy-specific causes of sepsis (chorioamnionitis, postpartum endometritis) (1C).

Experience with activated protein C is limited to case reports; use with caution (2C).

45 Ultrasound in the intensive care unit
Kazuhide Matsushima and Heidi L Frankel

A 65-year-old obese male with ascending cholangitis is admitted to the surgical intensive care unit (SICU). His skin is clammy, and peripheral pulses are rapid and shallow. The blood pressure is 80/72 mmHg and heart rate is 112 bpm. He is a candidate for early goal-directed therapy whereby invasive access is required to monitor the central venous pressure (CVP) and venous oxygen saturation. Given his body habitus, central venous cannulation seems to be difficult. A portable ultrasound (US) is available in the SICU.

SHOULD ULTRASOUND GUIDANCE BE USED FOR CENTRAL VENOUS CANNULATION REGARDLESS OF LINE LOCATION?

Central venous cannulation is one of the most common procedures in the ICU setting. Although the utility of central venous access is unquestioned for secured intravenous administration of vasopressors and as a hemodynamic monitoring device, cannulation may result in several mechanical complications that can lead to a catastrophic outcome.(1) Historically, performing a blind puncture procedure depended greatly on precise knowledge of vascular anatomy and clinical experience.(2) Today, in contradistinction, US-guided central venous cannulation can improve the successful cannulation rate and reduce the risk of insertion related complications. Furthermore, US guidance shortens procedure time and diminishes punctures. In 2002, the U.K. National Institute of Clinical Excellence (NICE) guidelines recommended the use of US guidance for insertion of central venous catheters in the internal jugular location.(3) Table 45.1 shows a summary of GRADE system recommendations for US-guided central venous cannulation.

Frequently used sites for the central venous cannulation include the internal jugular vein, subclavian vein, and femoral vein. The selection of cannulation site is based on the relative risk of complications that are mechanical (pneumothorax, hemothorax, arterial puncture, etc), infectious or thrombotic.(4–6)

INTERNAL JUGULAR VEIN

The internal jugular vein (IJV) is the most studied site for US-guided cannulation. Several landmark puncture techniques have been described to accomplish cannulation.(7) The most common one is to insert the needle just lateral to the pulse of common carotid artery (CCA). However, up to a quarter of IJV are not lateral to the CCA.(1) In the US-guided technique, the transducer probe is placed transversely on the neck to obtain a cross sectional image of the IJV and CCA. The probe is then rotated 90 degrees to obtain a longitudinal image of the IJV. After obtaining the anatomical information regarding the position of the IJV relative to CCA and excluding the presence of venous

Table 45.1 Recommendation of Ultrasound-Guided Central Venous Cannulation.

Site	Technique	GRADE Recommendation	References
Internal jugular vein	Real-time	1A	9–19
	Pre-procedure	2B	8
Subclavian, Axillary vein	Real-time	1B	26
	Pre-procedure	2B	23
Femoral vein	Real-time	1B	33,34
	Pre-procedure	N/A	N/A

N/A: not available.

thrombosis, a needle puncture is performed with or without real time US monitoring. A standard Seldinger technique is used to advance the catheter.

One prospective randomized study of patients under general anesthesia revealed that when the IJV dilated upon inspiration (implying adequate volume status), there was no difference in first attempt success (85.7% in the US group vs. 83.5% in the landmark group), and arterial puncture rate (3.3% vs. 1.0%) between patients undergoing US imaging or not. However, if the IJV did not dilate (implying hypovolemia), a higher first attempt success rate (86.2% vs. 30.4%, P < 0.001) and success rate within three attempts (100% vs. 78.3%, P < 0.05) was identified with US imaging.(18)

Landmark Technique vs Real-time Ultrasound-guided Technique

In the last two decades, several prospective randomized trials reported the effectiveness of a real-time US technique for the internal jugular vein cannulation.(8–19) A diverse group of patients not limited to critical care but also including hemodialysis (18), elective surgery (8, 17), and pediatric patients (14), have been investigated. Karakitosos and colleagues (9) conducted a prospective randomized study that included 900 critical care patients. They found that real-time US-guided cannulation of the IJV is superior to the landmark technique for several outcome variables in mechanically ventilated critical care patients. In addition to the improved overall success rate (100% vs. 94.4%, P < 0.001) and access time (17.1±16.5 vs. 44±95.4, P < 0.001), mechanical and infectious complication rates were also significantly lower in the US than the landmark group. Furthermore, in 34 patients in the US group, real-time imaging detected the presence of thrombus and prevented an unnecessary puncture. Of course, the investigators did not compare real time to pre-procedure imaging. A meta-analysis of US guidance for central venous cannulation by Hind and colleagues (20) concluded that real-time US-guided cannulation is associated with improved

outcome. Real-time US guided IJV cannulation was associated with a lower risk of overall cannulation failure (relative risk (RR) = 0.14, 95% CI = 0.06–0.33), complications (RR = 0.43, 95% CI = 0.22–0.87), reduced first attempt failure (RR = 0.59, 95% CI = 0.39–0.88), and reduced number of attempts (1.5 fewer attempts, 95% CI = 0.39–0.88); however, most comparisons were to landmark technique and not pre-procedure imaging.

SUBCLAVIAN VEIN, AXILLARY VEIN

Subclavian vein catheterization is a commonly used procedure in ICU due to the higher infection rate associated with IJV catheters.(21) Furthermore, concomitant procedures being performed around the ICU patient's head (such as intracranial pressure monitor insertion or endotracheal tube intubation) may make subclavian vein cannulation more attractive than IJV use. But the potential risk of major complications and cannulation failure is real, especially for less experienced operators.(22) Mechanical complications related to subclavian vein cannulation include arterial puncture, hemothorax, pneumothorax, mediastinal hematoma, and catheter misplacement.(23) The subclavian vein is usually approached through the infra-clavicular route. The needle is inserted at the midportion of the clavicle and advanced under the clavicle toward the sternal notch. Since the subclavian vein is located underneath the clavicle, the penetration of the US beam is difficult. The axillary vein extending from the outer border of teres major to the outer border of the first rib is the continuation of subclavian vein.(24) Use of the landmark technique to identify the axillary vein was suggested by Nickalls (25), but has not become popular due to its anatomical variability. US-guided axillary vein cannulation can be performed more easily because the lateral location is easily demonstrated with US. The patient is placed in the Trendelenburg position and a cross-sectional image of the axillary vein and artery is obtained caudal to the lateral aspect of the clavicle using a sterile sheathed 7.5-MHz linear transducer probe. Normally, the axillary artery is located cephalad to the vein and has a smaller diameter. Then, the axillary vein is examined longitudinally with assessment of compressibility. The needle is inserted after a skin mark or under the direct vision of US. A prospective randomized trial by Mansfield and co-authors (23) found no benefit for pre-procedure US-guided technique compared with landmark technique for the subclavian vein cannulation. Complications occurred in 9.7% of patients in the US group and 9.8% in the landmark group (risk ratio = 1.00, 95% confidence interval, 0.66–1.52). The rates of cannulation failure were 12.4% in the US group and 12% in the landmark group (risk ratio = 1.04, 95% confidence interval, 0.72 to 1.50). For less experienced operators such as resident physicians, a significant increase in successful catheterization rate with real-time US-guided subclavian vein cannulation was reported (92% vs. 44% in landmark group, P = 0.0003) by Gualtieri et al.(26) Furthermore, 80% of the failed attempts by the landmark technique were successfully placed with US guidance by same operator. The average number of attempts was also significantly reduced in the US group (1.4 vs. 2.5, P = 0.0007). The complication rate was reduced from 41% to 4%. Sharma and co-authors (27) reported 200 consecutive axillary vein cannulations with a 96% success rate and 2.5% complication rate using

US guidance. A randomized prospective study by Lefrant and colleagues (28) revealed that the total successful catheterization rate, successful catheterization at first attempt, and the number of skin punctures were the same in standard B Mode and pulsed Doppler US guidance cannulation. Another prospective, randomized trial also failed to provide any benefit of pulsed Doppler US compared with standard B-mode US.(29)

FEMORAL VEIN

Although femoral vein cannulation is a less preferred site for long-term placement because of its high infection rate (30), the femoral route is commonly attempted in an emergency situation, especially during CPR or limited access cases because of its rapid accessibility.(31, 32) In the landmark technique, needle insertion into the femoral vein is performed medial to the pulse of superficial femoral artery inferior to a line drawn between pubic tubercle and anterior superior iliac spine. To date, few data regarding the utility of US in femoral vein cannulation have been reported. Kwon and co-authors (33) demonstrated that first attempt success rate and total procedure time have been improved using US guidance for femoral vein cannulation for hemodialysis access (92.9% and 45.1±18.8, respectively). While 89.5% of patients were ultimately successfully cannulated using the landmark technique, all cannulation was achieved in the US-guided group. In patients sustaining cardiopulmonary arrest, Hilty and colleagues (34) demonstrated fewer needle passes (2.3±3 vs. 5.0±5, P = 0.057) and an arterial catheterization (0% vs. 20%, P = 0.025) using US guidance compared to the landmark technique.

HOW SHOULD ULTRASOUND BE PERFORMED? (PRE-PROCEDURE OR REAL-TIME?)

When performing the US-guided central line catheter insertion, real-time US imaging or a pre-performed image can guide needle puncture with skin marking.

Pre-procedure Technique (Skin Marking)

A nonsterile US scan is performed before puncture to assess the anatomical position of the neurovascular structures. Visible skin marking is made at two points between the proximal and the distal end of the vessel in question. After skin preparation, needle puncture is guided by the skin mark over the course of the vein.

Real-time Technique

A 7.5-MHz linear transducer probe, covered with a sterile plastic sheath, is placed over the vessels. The insertion of needle is performed under direct visualization keeping the transducer probe in line. The probe can be applied longitudinally or cross-sectionally to image the vessel. One operator technique (one hand holding the probe and the other hand inserting the needle) or two operator technique (one for holding the probe and the other for inserting the needle) are possible. The tip of needle penetrating the anterior wall of vessel should be visualized (easier in longitudinal imaging). Then catheterization is performed using Seldinger technique.

To date, there are insufficient data to compare the outcome between real-time and pre-procedure imaging techniques. In pediatric patients, Hosokawa and co-authors (35) compared

the outcome of real-time technique with skin surface-marking technique in a prospective, randomized trial. Total successful cannulation rate was 100% (33/33) in real-time group and 89% (24/27) in skin surface-marking group (P = 0.19). Complication rate were 0% and 7%, respectively (P = 0.20). On the other hand, the time to successful puncture and catheterization were significantly shorter in the real-time group than in the skin surface-marking group. In adult patients, the Third Sonography Outcome Assessment Program (SOAP-3) trial (12) demonstrated the total successful cannulation rate of real-time, skin marking, and landmark techniques were 98%, 82%, and 64%, respectively. The first attempt success rate was 62%, 50%, and 23%. The complication rates were 3%, 3%, and 13%. Of note, 13 failed cannulations in the skin-marking group were successfully cannulated using a real-time technique.

To our best knowledge, no reports comparing the outcome of cannulation between pre-procedure technique and real-time technique in subclavian (axillary) vein and femoral vein have been reported. The real-time imaging technique is used in almost all newly published investigations.(9, 12, 17)

Nowadays, real-time puncture technique is widely used in the ICU setting. The National Institute for Clinical Excellence guidelines in the United Kingdom recommends the use of the real-time US-guided technique for central venous cannulation.(3) Given the data compared with landmark technique, real-time technique may be more preferable technique than the pre-procedure technique.(8, 23)

WHAT TRAINING AND CREDENTIALING IS REQUIRED?

US examination should be performed and interpreted by well-trained physicians. Traditionally, US has been performed by specialists such as cardiologists, radiologists, or obstetrician/gynecologists.(36) Although credentialing processes are established in several institutions, there are no widely accepted criteria.(37) Given the provider-dependent outcome of US, competency based credentialing should be the goal.

Currently, few critical care fellows or intensive care physicians have an opportunity to undergo adequate training in US or echocardiography in the USA. The US training courses have been developed in each area of specialty. The professional societies in United States have developed training and competency guidelines in US.(38–40) In the area of emergency medicine, the utility of US by emergency physicians has dramatically increased over the last two decades.(41) In 95% of emergency medicine residency program in US, teaching of bedside US, either clinically and/or didactically, is included as part of the curriculum.(42) Meanwhile, about a half of the US general surgery residents received US training other than Focused Assessment for the Sonography of Trauma (FAST).(43) In 1998, the American College of Surgeons (ACS) developed a voluntary verification program for surgeons in the use of US.(44) Educational programs provided by ACS include a basic core module, acute, vascular, and abdominal, (transabdominal/intraoperative/laparoscopic) anorectal, head and neck, breast, and an instructor's module.

In Europe or Australia, US training courses and an accreditation process for emergency and intensive care providers has already been provided and several hundred intensivists have trained to an advanced level.(45–47) The courses include pre- and post course examinations to assess basic knowledge about US. Different types of training are required for each level of accreditation (Level 1–3) in the specified areas.(47, 48)

Despite aggressive volume resuscitation, the patient remains hypotensive. The patient has a history of coronary artery disease that was treated with angioplasty in the remote past. You are uncertain as to the etiology of shock. Is the patient still hypovolemic or is he in cardiogenic shock?

HOW MIGHT ULTRASOUND BE USED TO ASSAY VOLUME STATUS? CARDIAC FUNCTION?

Estimation of volume status and cardiac function in critically ill patients is a deceptively difficult task. Both overestimation and underestimation of function and volume status can lead to unfavorable patient outcome. Inappropriate infusion of vasopressors into hypovolemic patients can cause serious global or regional ischemia. On the other hand, excessive hydration for the patient with reduced cardiac function can result in worsening of heart failure. Currently, several methods are used to evaluate volume status, including CVP and pulmonary artery catheter (PAC) monitoring, arterial line, or CVP waveform interpretation, transthoracic echocardiography (TTE), and transesophageal echocardiography (TEE). Invasive intravascular hemodynamic monitoring infers information on volume status through pressure measurement. However, these pressure measurements correlate poorly with true ventricular volume (preload).(49) Although the PAC has been used as a guide to resuscitation in the ICU, several randomized control trials have failed to demonstrate an improved outcome in critically ill patients so monitored.(50–52) Furthermore, the incidence of pulmonary embolism has been shown to be higher in PAC group.(53)

Echocardiography provides real time information of cardiac anatomy, physiology, and function. It may be performed at bedside and could become a more pivotal imaging modality for critically ill patients.

Historically, cardiologists have interpreted comprehensive echocardiography performed by technicians. However, focused bedside echocardiography performed by well-trained intensivists can be an effective alternative in the ICU setting.(45) Intensivist-performed focused echocardiography has been shown to be useful for predicting the volume status and cardiac function in ICU patients. Carr and colleagues (54) reported the feasibility of clinician sonographer (CS)-performed cardiac and IVC US for volume assessment in the critically ill surgical patients. Their prospective cross-sectional study demonstrated that CS obtained adequate images in 96% of cardiac and 89% of IVC views. The concordance rate between clinical judgment and CVP, and clinical judgment and US measurements were similar.

One of the bedside echocardiographic techniques is the so-called "BEAT" Exam or bedside echocardiographic assessment in trauma and critical care.(55) The letters in the name BEAT also stand for a specific step during the examination. Table 45.2 shows the component of BEAT exam. The examination is performed with a portable US device using a low frequency (2MHz to 5MHZ) cardiac transducer. Ideally, the patient is placed in the left lateral decubitus position for better cardiac image.

Table 45.2 Bedside Echocardiographic Assessment: BEAT Exam. (55)

Meaning of BEAT acronym	Goal	View	Task
Beat (cardiac index)	Cardiac function	Parasternal long	Stroke volume
Effusion	Pericardial effusion	Parasternal long	Subjective assessment
Area (ventricular size and function)	Right and left ventricle	Parasternal short Apical 4chamber	Subjective assessment
Tank (preload)	Volume status	M mode subcostal	IVC measurement

Beat: Cardiac Index

Stroke volume is measured by the fractional shortening (FS) technique. Determination of the FS percentage is a simple and accurate method in the ICU setting. In the left parasternal long axis view, 2-dimentional and M-mode echocardiography are used to measure the left ventricular end-systolic and end-diastolic diameter. The software package calculates the left ventricular stroke volume from these measurements. The cardiac index is calculated by the following formula:

$$\text{Cardiac index} = \text{Stroke volume} \times \text{Heart Rate} / \text{Body Surface Area}$$

Alternative techniques to estimate the cardiac index (2D:Simpson's method and Pulsed-wave Doppler: velocity time integral method) may also be used for the BEAT assessment.

Effusion: Effusion

Using the parasternal long axis view, presence of pericardial and pleural effusion are assessed. A pericardial effusion can be visualized as a hypoechoic area inside the pericardium and ventral to the descending aorta. A pleural effusion can be visualized outside the plane of the aorta.

Area: Ventricular Size and Function

By rotating the transducer 90 degrees from the parasternal long axis view, the parasternal short axis view is obtained. Subjective assessment of left and right ventricular function (dynamicity) and size are analyzed. The apical four-chamber view can be added for the assessment of right ventricle. In a normal heart, the size of right ventricle is approximately 60% of the left ventricle.

Tank: Preload

The inferior vena cava (IVC) diameter and the waveform of mitral valve are used for the assessment of the volume status. The transducer is placed in the epigastric area and a longitudinal IVC image is obtained. The diameter of IVC is measured at end-inspiration and end-expiration phases within two cm of its entrance into the right atrium. From this method, two variables are used to estimate the volume status. An IVC diameter smaller than one cm indicates a low CVP level, whereas a diameter above two cm implies a high CVP level.(56) A second parameter is the collapse

rate of IVC diameter with respiration. In spontaneously breathing patients, there is normal inspiratory decrease in the caliber of the IVC. In the patients on the mechanical ventilation, IVC is collapsed during expiration. More than 50% collapse is estimated to correlate with a low CVP level. In the parasternal long axis view, M-mode echocardiography or continuous wave Doppler is used to trace the mitral valve waveform. The relative sizes of the E and A waves (E/A ratio) that correspond to opening of the mitral valve resulting from early LV filling and atrial contraction, respectively, are used to estimate the volume status. Hypovolemia will reduce the E/A ratio.

BEAT was found to accurately characterize cardiac function and filling status in surgical and trauma patients.(57)

Sloth and colleagues are proposing another simple protocol for echocardiography in the ICU.(58, 59) This protocol, called FATE (Focused Assessed Transthoracic Echocardiography), is easy to learn and provides the usable images of US in 97% of patients. The FATE protocol summary card can be obtained through the FATE protocol website, www.fate-protocol.com.

> Forty-eight hours later, the patient previously described develops hypoxia. A chest radiograph reveals bilateral infiltrates. The respiratory therapist notifies you that the patient is now requiring FiO2 80%. What does infiltration represent? What is the etiology of hypoxia? (The patient is too unstable to be taken to the CT scan).

How might ultrasound be used to diagnoses a pulmonary embolism, pneumothorax, pneumonia, pulmonary edema or pleural effusion? Respiratory failure is one of the most common situations in the ICU. Conventionally, portable chest radiography has been considered to be the gold standard for diagnosis. But its limited reliability in the assessment of respiratory failure is reported in several studies.(60, 61) The evolution of Computed tomography (CT) has improved the accuracy of the diagnosis in the patient with respiratory failure. Multidetector-row CT scanning (MDCT) enables dramatically shorter scanning times and provides a variety of reconstructable views. However, CT scanning still requires transportation, which may not be possible in the unstable patients.(62)

The utility of US for diagnosing lung disease has been limited because bone and air were considered natural obstacles. Recently, in the trauma, emergency, and critical care setting, chest US has become more useful and an oft performed imaging modality.(63) Furthermore, bedside portable US examination can be repeated frequently as a patient's condition changes without a significant concern for the risk of ionizing radiation.

Normal Findings of Lung Ultrasound

In a normal lung examination, US waves are not transmitted through the parenchyma. Therefore, the detailed structure of lung cannot be visualized. Thus, the interpretation of certain imaging artifacts allows us to infer information about the lung. When the probe of US is positioned perpendicular to intercostal space, a hyperechoic and sliding line moving back and forth with respiration can be seen between the ribs, which is called "lung sliding".(64) This pleural line represents the movement between the
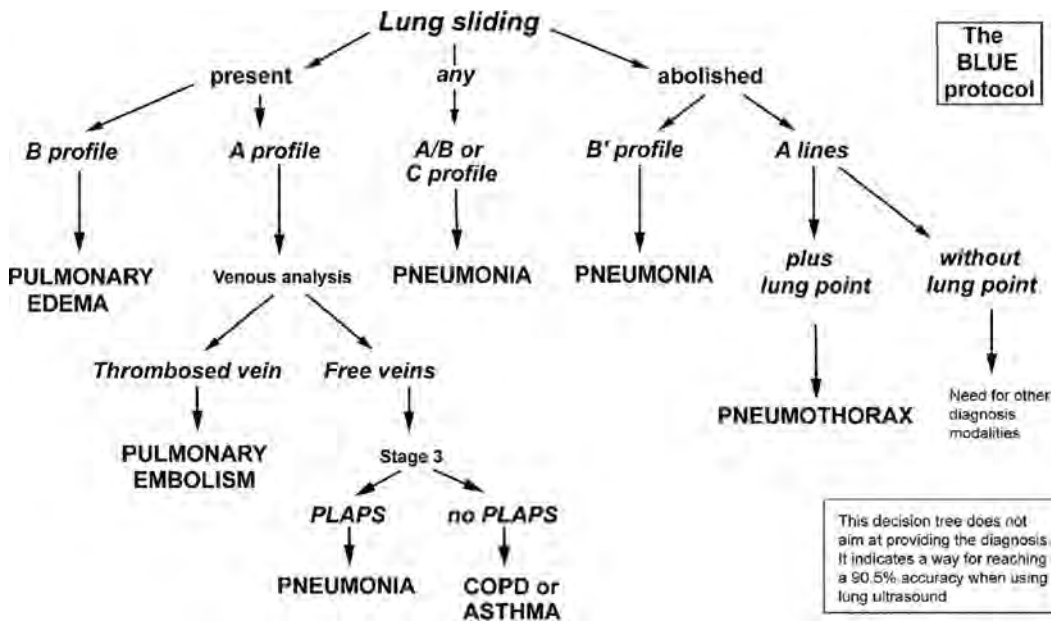
Figure 45.1 The diagnostic strategy using chest ultrasound (BLUE protocol). (74)

A profile: predominant A lines plus lung sliding at the anterior surface.

B profile: anterior interstitial syndrome with lung sliding.

B' profile: lung sliding abolished.

A/B profile: asymmetric anterior interstitial syndrome.

C profile: anterior consolidation.

PLAPS: predominant A lines plus lung sliding.

visceral pleura and the parietal pleura. One or two regularly separated hyperechoic horizontal lines are observable under the pleural line. These repetitive artifacts are called "A lines." (65) Another set of artifacts, called "B lines," or "Comet-tail artifacts" (66) are characterized as vertical, narrow-based, and hyperechoic lines arising from pleural line. These artifacts result from reverberation. On M-mode, motionless and regularly spaced horizontal lines are seen beyond the pleural line and a homogeneous granular pattern below it. This "seashore sign" represents the motionless body wall (wave-like pattern) and moving lung (sand-like pattern).(64)

Pneumothorax

Air is present between the visceral and parietal pleural space in patients with a pneumothorax. The prominent finding with US is loss of normal artifacts described above. There is a lack of lung sliding and comet tail artifacts as well as an absence of the seashore sign.(66) The "lung point" is a specific sign of pneumothorax, which is an inspiratory –synchronized change from normal lung pattern to the pneumothorax pattern (loss of lung sliding and comet-tail artifact).(67)

Although plain chest radiography is the primary imaging modality for the diagnosis of pneumothorax, its sensitivity is not satisfactory.(68, 69) Missed pneumothorax with plain radiography also known as occult pneumothorax, can easily deteriorate to a fatal tension pneumothorax in the patient undergoing mechanical ventilation. CT scan is considered most sensitive for pneumothorax, but its utility is limited in critically ill patients. Blaivas and colleagues (69) used the loss of lung sliding in US as the diagnosis of pneumothorax in trauma patients. They found that the sensitivity for US was 98.1% (95% CI = 89.9–99.9) and the specificity was 99.2% (95% CI = 95.6%–99.9%). The sensitivity for chest radiography was 75.5% (95% CI = 61.7%–86.2%) and the specificity was 100% (95% CI = 97.1–100%). In another prospective study of trauma patients, only 52% of pneumothoraces were revealed by plain chest radiography, whereas emergency room bedside US, which is typified by loss of lung sliding,

comet-tail artifacts and the presence of lung point, detected 92% of pneumothoraces.(70)

Pleural Effusion

Pleural effusion is a common complication in critically ill patients. Bedside focused thoracic US examination has been shown to accurately detect pleural effusions in trauma and surgical ICU patients.(71, 72) A 3.5-MHz transducer probe is placed at the ninth to tenth intercostal space in the mid to posterior axillary line. The probe is slowly moved cephalad to identify an anechoic area above the diaphragm. The adjacent lung is usually atelectactic, which can be seen as a consolidated hypoechoic pattern. Surgeon-performed US to detect the presence of a pleural effusion in the Surgical ICU revealed an 83.6% sensitivity, 100% specificity, and 94% accuracy.(73)

The intensivist can perform US -guided thoracentesis with a lower complication rate than with landmark technique. Two methods, direct and indirect, are available. The indirect technique is performed using US before puncture to determine the level of needle insertion (skin marking). The direct technique is performed under real-time vision of the US monitor during the needle insertion. The direct technique is preferred in the case of a small amount of pleural effusion or a loculated effusion. Liang and colleagues reported that 133 US -guided pigtail catheter drainages could be performed by intensivists without major complication.(74) A total of 77 patients (58%) were successfully treated with initial drainage. While traumatic hemothorax (100%) and postoperative effusion (85%) were often treated successfully, the drainage of empyema was more likely to fail (42%).

Alveolar Consolidation

Massive pulmonary edema, lobar pneumonia, pulmonary contusion or atelectasis will cause the loss of aeration in the lung. A loss of aeration in the lung with consolidation enables us to evaluate the parenchyma via US. The affected lung area is visualized as a hypoechoic structure that is poorly defined and wedge shaped.

US findings of lung consolidation are often similar to those of solid organs. The air bronchogram can be seen as hyperechoic punctiform images. Lichtenstein assessed the utility of ultrasonographic findings for the diagnosis of alveolar consolidation.(75) In a total of 65 cases of CT proven alveolar consolidation, the sensitivity of US was 90% and specificity 98%.

A systematic approach for acute respiratory failure with bedside US is required in the critical care setting. The BLUE protocol, which corresponds to Bedside Lung US in Emergency, is one example of guiding the diagnosis of acute respiratory failure.(76) Figure 45.1 shows the decision-making tree of BLUE protocol. The observational study using the BLUE protocol resulted in high diagnosis rate (90.5%) for the most common etiologies of acute respiratory failure. Bedside US should be considered as a primary diagnostic modality for the patient of respiratory failure.

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46 Appendicitis
John W Mah

A 45-year-old female presents to the emergency department with 6 days of worsening abdominal pain and fever. The pain was generalized and crampy at first but now is constant, getting worse and has localized to the right lower quadrant (RLQ). She denies nausea and vomiting but has no appetite. She has an oral temperature of 101.7°F.She is tachycardic to 100 beats/min, slightly hypertensive at 160/70 and has a respiratory rate of 25 breaths/min. Her physical examination is remarkable for tenderness in the RLQ of her abdomen with guarding but no rebound, with some distention but no palpable masses. There is also pain with palpation to the left lower quadrant but less severe. Her laboratory workup is significant only for a white blood cell (WBC) count of 18,000 with 80% polymorphonuclear cells (PMNs). A computed tomography (CT) scan is ordered and reveals a significant amount of fat stranding in the RLQ consistent with a phlegmon, but the appendix is not well visualized and there is n o clear abscess. The patient is given 2 l of lactated ringers, IV ceftriaxone, and metronidazole in the emergency department and brought immediately to the operating room and is explored laparoscopically. Purulent fluid is seen on entry to the abdomen with adhesions present in the RLQ surrounding an inflamed cecum and terminal ileum. After much manipulation the appendix is visualized and found to be grossly inflamed and perforated at the base of the cecum. The surrounding tissue is difficult to handle due to the inflammation and adhesions. Subsequently, a midline incision is made and an ileocecectomy is performed with a primary anastamosis. The abdomen is irrigated thoroughly with normal saline, and the abdomen and skin are closed. The patient is slow to progress, and continues to have a persistently elevated WBC and develops a temperature of 102.1°F on postoperative day 5. Her wound becomes erythematous and is opened revealing a moderate amount of purulent drainage initially and subsequently remains clean with local wound care. Her fever abates and WBC count normalizes and she regains bowel function on day 7. She is tolerating regular food and is discharged to home on hospital day 9 with local wound care.

BACKGROUND

From the first accurate description of the diagnosis and treatment of appendicitis in 1886 by Reginald Fitz, the surgical technique for appendectomy has progressed from its basic form to the refined muscle splitting surgical technique of McBurney to the current laparoscopic technique first introduced by Semm.

(1, 2) Appendectomy continues to be the procedure of choice for appendicitis and still remains the most common intra-abdominal condition requiring emergency surgery. The lifetime risk of appendicitis is 8.6% for males and 6.7% for females with a peak incidence occurring from age 10 to 19.(3) In fact, 12% of males and 23% of females will have an appendectomy over the course of a lifetime. Patients often do not present with classic signs and symptoms and the diagnosis and treatment decisions can become challenging. This is observed especially in patients at the extremes of ages, during pregnancy, morbid obesity, and can be further complicated by the presence of a phlegmon, perforation, or abscess. This chapter will focus on the diagnostic and therapeutic challenges of appendicitis.

DIAGNOSIS

No specific test exists for the diagnosis of appendicitis yet, and the diagnosis still largely remains a clinical one. However, the clinical presentation is frequently not typical, and signs and symptoms are often only subtle. Moreover, due to the lack of consistent classic clinical findings, radiological and laboratory tests are still needed to aid in diagnosis with varying degrees of predictive value.

She is tachycardic to 100 beats/min, slightly hypertensive at 160/70 and has a respiratory rate of 25 breaths/min. Her physical examination is remarkable for tenderness in the RLQ of her abdomen with guarding but no rebound, some distention and no palpable masses. There is also pain with palpation to the left lower quadrant but less severe. Her laboratory workup is significant only for a white blood cell (WBC) count of 18,000 with 80% polymorphonuclear (PMN) cells.

HOW IS THE DIAGNOSIS CONFIRMED?

Clinical and Laboratory Tests

Individually, clinical signs and symptoms and laboratory tests have had poor predictive value, however when combined together they are able to reach a higher discriminatory value. Particularly useful are of course a history of pain consistent with the characteristic migration of pain, an exam that demonstrates peritoneal irritation, and presence of anorexia. Also note that some findings, such as rebound tenderness, involuntary guarding, and pain outside the RLQ, tell us of more advanced disease states such as perforation, phlegmon, and abscess.(4) Urinalysis, pregnancy testing, and other laboratory testing are more often helpful in excluding other diagnoses. Approximately 10% of emergency department patients complaining of abdominal pain are found

Sign/Symptom/Test	Score
Pain migration to the RLQ	1
Anorexia	1
Nausea/Vomiting	1
Tenderness at McBurney's point	2
Rebound tenderness	1
Fever (> 37.3C)	1
Leukocytosis > 10 x 109/L	2
Neutrophil count >= 75%	1
Total	**10**

Figure 46.11 Alvarado Score.

to have a urinary tract disorder, but appendicitis may be the cause for pyuria, bacteriuria, or hematuria in up to 40% of cases.(5, 6) A urine red blood cell (RBC) count > 30 cells or WBC count > 20 cells per high-powered field is more indicative of a urinary tract source. There is evidence that laboratory tests of the inflammatory response are helpful and may be as valuable as the abdominal exam in predicting or ruling out appendicitis. Nonspecific tests of the inflammatory response such as C-reactive protein (CRP) have been recently shown to correlate with appendicitis but have not reached widespread use. Leukocytosis with an increase in the PMNs > 75% is present in 80–90% of cases. Perhaps more importantly, appendicitis appears to be very unlikely in a patient with a normal WBC count and nonelevated PMNs.(7) Of course leukocytosis is present in many acute abdominal disease states and should not be used alone do differentiate the disease process. The Alvarado score first published in 1986 (Figure 46.1) attempted to predict the likelihood of acute appendicitis using history, physical exam, and simple laboratory testing using a 10-point scoring system.(8) Patients with scores of 7 or higher were more likely to have acute appendicitis and warranted immediate surgical consult without further radiologic imaging, and scores of 3 or less were unlikely to have appendicitis; the equivocal score fell between 4 and 6.

Radiologic Imaging

Imaging studies for suspected appendicitis are being ordered more and more frequently and have even been advocated by some for routine use.(9) Imaging itself can occasionally lead to more unanswered questions with nondiagnostic findings, such as increased appendiceal diameter or nonvisualization of the appendix with or without isolated RLQ fat stranding only. Nonetheless, use of imaging to aid the diagnosis for appendicitis has increased dramatically. Results from an analysis from 1991 to 1999 showed a threefold increase in the usage of preoperative CT or ultrasound (US) for appendicitis. Despite this rapid growth in imaging, the negative appendectomy rates have remained unchanged for virtually the same time period from 1987 to 1999.(10) Still CT and US both have good positive predictability at 97% and 94%,

respectively. More evidence has suggested that CT is more sensitive, specific, and accurate than US as well as more likely to detect an intra-abdominal abscess or phlegmon or an alternative diagnosis.(11–15) However, a negative test cannot rule out appendicitis and can still be associated with appendicitis in 12% of patients after CT and 30.5% of patients after US.(10) Furthermore, it is often unclear how to proceed and what the clinical consequences are when CT findings are equivocal or nondiagnostic findings exist. Daly et al. reviewed 1,344 CT scans of patients with the indication of suspected appendicitis with equivocal findings in 13% or 172 scans. Of those with equivocal CT findings, appendicitis was still found in 31%. Other factors such as appendiceal size have been used diagnostically with an average appendiceal diameter of 6 mm but studies of normal adults range from 3 mm to 10 mm.(16) In this same group of patients with equivocal CTs, appendiceal diameter on CT greater than 9 mm resulted in appendicitis 50% of the time, but still occurred in 13% of those with an appendiceal diameter less than 9 mm. Thus a significant overlap in appendiceal diameter exists between normal and abnormal appendices and size alone should not be used to confirm the diagnosis, but the diagnosis should also be based on appearance and presence of any other secondary signs of disease. (16) Appendicitis can still occur even when the appendix is not visualized on CT and no other findings are present. Fortunately, this event is seen in less than 2% of patients.(17, 18) However, nonvisualization with any amount of RLQ stranding or fluid resulted in appendicitis in 44% of patients.(19) CT is superior to US in correctly identifying appendicitis in adults, CT is likely to be more useful at the extremes of ages, and surgical evaluation prior to imaging may help reduce the number of unnecessary CT scans. Although many have advocated for the routine use of radiologic imaging for appendicitis, several studies have shown that routine imaging often adds minimally to the diagnostic accuracy for appendicitis and that an accurate history and physical are oftentimes all that are needed to attain the diagnosis.(20)

> The patient is given 2 l of lactated ringers, IV ceftriaxone and metronidazole in the emergency department and brought immediately to the operating room and explored laparoscopically. Purulent fluid is seen on entry to the abdomen with adhesions present in the RLQ surrounding an inflamed cecum and terminal ileum. After much manipulation the appendix is visualized and found to be grossly inflamed and perforated at the base of the cecum. The surrounding tissue is difficult to handle due to the inflammation and adhesions.

IS THERE AN ADVANTAGE OF LAPAROSCOPIC VERSUS OPEN APPENDECTOMY?

Semm first introduced the laparoscopic appendectomy (LA) in 1983, with the advent and worldwide acceptance of laparoscopic surgery.(2) The number of appendectomies performed laparoscopically has since then increased dramatically around 19–38% from 1997 to 2003.(21) Unlike laparoscopic cholecystectomy, which has received wide acceptance for the treatment of acute cholecystitis, LA for appendicitis is not the universal benchmark.

This lack of acceptance stems from conflicting data regarding the advantages of LA over the traditional open technique in terms of hospital length of stay (HLOS), postoperative intra-abdominal abscesses, and cost.

A Cochrane review (22) of LA versus conventional open appendectomy (OA) examined 54 randomized control trials (RCTs) supported LA when compared with OA. The review suggests that operating time with laparoscopy was on average 12 minutes longer, patients required less analgesia, and wound infections were 50% less likely. However, intra-abdominal abscess formation was threefold higher after LA. In addition, return to normal activity was 6 days (95% CI 4–8) earlier after LA and return to sporting activity was quicker. Operative cost and hospital costs were found to be higher in the LA group when compared with OA, however, the heterogeneity of the health care systems in these analyses makes it difficult to make any generalizations. Also, the increase in availability and decrease in costs with laparoscopic equipment may eventually result in a decrease in the operative cost of LA, and in fact, some studies suggest that out of hospital costs are decreased especially in the employed population. (23) Notably, the clinical trials in the Cochrane review involved laparoscopic surgeons who were well-trained in laparoscopy and this prerequisite must exist in order to apply these findings and experience to the same benefit. The Cochrane review would support performing LA when qualified and trained laparoscopic surgeons and the appropriate equipments are available, and no other contraindications exist. Furthermore, since the overall benefits of LA were small, those who do not posses an adequate skill set for LA can and should continue to perform OA. Perforated and gangrenous cases were excluded in these recommendations with findings of higher risk of postoperative abscess.

More recent literature continues to support the position that LA is safe and also suggest that intra-abdominal abscesses occur more frequently in this group, up to 14% in complicated appendicitis.(24–27) It is not clear however if this increased abscess rate is related to patients with complicated appendicitis rather than laparoscopy method itself.(28) Also laparoscopy should be the operative preferred procedure for women and the morbidly obese with suspected appendicitis.(29, 30, 56) Laparoscopy for appendicitis, nonetheless, is becoming more prevalent, with many centers performing it routinely also noting that laparoscopy allows for better visualization of the appendix and the remaining abdominal cavity, discovery of other potential diagnoses, and improved ability to irrigate and lavage the abdomen.

WHAT ARE SPECIAL POPULATION-BASED CONSIDERATIONS IN DIAGNOSIS AND TREATMENT?

Appendiceal Mass
Delayed presentation in patients with appendicitis can produce continued, persistent inflammation with resulting phlegmon, perforation, abscess, and often an appendiceal mass, either by physical exam or radiologic imaging. Initial management is controversial and involves either immediate exploration often ending in ileocecectomy or right hemicolectomy due to the intense inflammatory reaction at the base of the appendix and the inability to close the appendiceal stump or nonsurgical management that may or may not be followed by an interval appendectomy.

In a review and meta-analysis of 61 studies reporting results of nonsurgical management of advanced appendicitis, the total incidence of appendiceal abscess or phlegmon was 3.8% with 20% needing percutaneous drainage.(31) Failure rate or early recurrence of appendicitis was 7.2%. Total morbidity of nonoperative treatment including recurrence, infections, intestinal fistulas, and bowel obstructions was relatively low when compared with immediate surgery (13.5% vs. 35.6%). Of note, those that went on to interval appendectomy were subject to an additional 11% morbidity but still have significantly lower complications from immediate surgery in this study. An alternative diagnosis was found at follow-up in 2% of the nonsurgical patients; 1.2% had malignancies and 0.7% had Crohn's disease. When adjusted for age, cancer was found more frequently in patients older than 40 years, but it did occur in two children (0.2%) and two adults under 40 years of age (gastric, ovarian cancer). Although there are some conflicting studies that have demonstrated that ileocecectomy for advanced appendicitis can be done with acceptable morbidity and offers definitive treatment with the best complication rates ranging 12–25%, some reports have been as high as 67%. (32–34) However, not included in this data set are the numbers of diverting ileostomies (5–18%) required at initial operation. No definitive conclusions regarding HLOS have been made but numbers vary widely within each group. Advanced appendicitis can be managed successfully with conservative management with some patients requiring percutaneous drainage. The majority of studies have associated nonsurgical treatment with lower morbidity and shorter HLOS. Immediate surgical management appears to be associated with higher morbidity and a small but significant incidence of diverting ileostomy both at initial operation and created after postoperative complications. One must also strongly consider follow-up imaging or colonoscopy in those patients older than 40 years not undergoing interval appendectomies for the small but real incidence of malignancy and must also consider the possibility of Crohn's disease.

Appendicitis in Pregnancy
Occurring once in every 1,000–1,500 pregnancies, appendectomy is the most common emergent surgical procedure performed during pregnancy with equal distribution in all three trimesters. (35) It still remains a significant diagnostic challenge with serious consequences resulting not only from complicated appendicitis and rupture but also from a negative exploration. Diagnostic accuracy remains poor for many reasons with reports ranging 50–75% making the correct diagnosis.(36–38) The position of the appendix varies as uterine size increases. The mild leukocytosis is difficult to interpret in pregnancy. Anatomically, as the peritoneum is "lifted" off the appendix as the uterus enlarges, it makes localization of pain more difficult.(39) Thus, the usual clinical markers of fever, peritoneal irritation, and leukocytosis are often unreliable.(40)Partly due to the reported higher incidence of perforation in pregnant patients, surgical management has been directed at prevention of appendiceal rupture and its association with higher maternal and fetal mortality.(41, 42) Fetal loss rates range 20–35% with perforation compared with 2–3% that are

nonperforated.(43) However, with improvements in medical care, maternal mortality has been decreasing from a historical 40% in 1908 to as low as 0% and cannot be used solely to rationalize surgical exploration. A large retrospective study investigated the complication rates of 94,789 women with appendicitis in the entire state of California from 1995 to 2002, of which 3,133 were pregnant.(44) The study confirmed the diagnostic challenges that still exist showing higher rates of negative appendectomies occurring in pregnant women undergoing appendectomy compared with nonpregnant patients. (23% vs. 18%; $p < 0.05$). An exploration with a negative appendectomy was not benign and was associated with a fetal loss rate of 4% which was more than the 2% occurring when simple appendicitis was found, but less than the 6% in patients with complicated appendicitis. The authors suggest that a statistically significant number of pregnant patients undergoing operation for appendicitis may be at least potentially putting their fetus at unnecessary risk and suggest that improvements could be made by increasing diagnostic accuracy. Conversely, although improvements in diagnostic accuracy would help to decrease the overall negative appendectomy rate, there is evidence that in populations with acute appendicitis, the perforation rates may actually increase as accuracy increases.(45)

With an uncertain diagnosis, care of each patient must be individualized, and occasionally a period of observation may be necessary if the findings are equivocal. However, diagnostic accuracy may be improved with direct imaging of the abdomen. MRI and US have been recommended by the American College of Radiology in pregnant patients due to their nonionizing radiation and potential fetal protection.(46) For RLQ pain in pregnancy, US performs very well and has been suggested as the first line imaging modality.(47, 48) Of note, nonvisualization of the appendix seems to occur more often with increasing uterine size as the appendix is displaced. MRI has been gaining favor with some studies demonstrating superiority to US with 100% sensitivity, specificity, and positive and negative predictive values when the appendix was visualized.(49) Gadolinium crosses the placenta, enters the circulation, is excreted in the urine, and is swallowed by the fetus, and this should be generally avoided in pregnancy, especially in the first trimester. MRI has also been shown to accurately diagnose other intra-abdominal causes such as abscess, torsion, and leiomyomas. CT can be used if MRI and US studies are unclear or these modalities are not readily available but has more potential teratogenic and carcinogenic risks. All imaging studies seem to be problematic during the third trimester with perhaps MRI and CT having a higher yield than US in this group, but it would seem wise to discuss these options with an experienced radiologist to determine the most appropriate study.(50)

Although we are not aware of any prospective RCTs directly comparing laparoscopic and open techniques for appendectomy in pregnancy, literature reviews have demonstrated a fetal loss rate of 5–7% with the laparoscopic approach.(44, 51, 52) The most recent review of 28 articles and 637 cases of appendicitis in pregnancy determined that the rate of fetal loss was almost 6% after LA and suggests that open surgery may be a safer option. (51) In the California experience the rate was 7% laparoscopic versus 3% open.(44) Still some centers have reported success with

the laparoscopic technique with increasing difficulty beyond the first trimester and suggest specific surgical alteration in this population. A Hasson approach may be safer than Veress needle; the patient should be placed in a left lateral decubitus position to displace the uterus off the vena cava and appendix, and the abdominal pressure should not surpass 12 mmHg.(52) It is uncertain if laparoscopy increases the risk of fetal loss and prospective RCTs will be hard to complete due to the relatively low occurrence of this condition. One thing is certain, operative treatment must ensue once the diagnosis is made without delay, with the only exception of concurrent labor.

Obesity

Morbid obesity is becoming an increasingly more common condition in patients requiring emergent surgery and often carries the corresponding comorbidities that increase their overall risk and mortality in gastrointestinal surgery.(53, 54) In general, severely obese patients (with body mass index [BMI] > 40 kg/m^2) have a higher incidence of cardiovascular disease, hypertension, congestive heart failure, diabetes mellitus, gastroesophageal reflux, obstructive sleep apnea, pulmonary hypertension, and right ventricular failure.(54) In 2007, 25.6% of the U.S. population was found to be obese (i.e. with BMI > 30).(55) Although few studies currently address complications associated directly with appendicitis, two recent retrospective reviews have evaluated the laparoscopic versus open approach to appendectomy in this patient population. Both studies found that LA was associated with shorter HLOS, decreased wound infections, equivalent incidence of intra-abdominal abscess formation, and equal if not lower in hospital costs.(56, 57) Only one of these studies used an actual definition of obesity defined as a BMI of ≥ 30. Other general risks apply to the obese surgical patient including a higher incidence of postoperative atalectasis and increased risk of deep vein thrombosis (DVT) and pulmonary embolus, that may be, at least partially, due to ambulatory difficulties.(54, 58, 59) Although no studies have clearly demonstrated an increased surgical mortality due to obesity alone, particular attention must be given to cardiac function, DVT prophylaxis, and appropriate antibiotics prior to administration of general anesthesia and careful positioning intraoperatively to avoid pressure sores and nerve injuries.(54, 58, 59)

The Elderly

Although appendicitis is mainly a disease of the younger population, the frequency seems to be increasing in the elderly in line with increasing life expectancy. Elderly patients with appendicitis have been shown to have higher morbidity, mortality, and increased HLOS with perforation rates in the elderly ranging as high as 50–70%.(60, 61) Because treatment and outcomes for perforated appendicitis have not changed significantly, more focus has been directed toward earlier diagnosis and prevention of this unfortunate consequence. The causes of these undesirable outcomes have been attributed to delay in presentation to the hospital with reports of more than half of elderly patients presenting with appendicitis 2 days after the onset of symptoms. However, a delay in diagnosis also exists in this population possibly related to

the higher incidence of coexisting illnesses, atypical presentation, accuracy of the history, and blunted febrile response. Coexisting illnesses have been found to be present in 44–65% of elderly patients with abdominal pain which increased the use of differential diagnosis. Presentation commonly lacks the classic findings and is often atypical with milder symptoms, absence of anorexia, and varying degree of leukocytosis and fever.(62, 63) In a review of 113 patients older than 60 years that underwent appendectomy, the diagnosis was incorrect in 54% resulting in a significant delay in time to operation.(64) Of these patients, 24% had a delay greater than 24 h and 73% of this group had perforated appendicitis. The most common misdiagnosis in this perforated group was bowel obstruction with diverticulitis, the most common misdiagnosis in nonperforated cases. Fever (> 37.6°C) was present in only 37% of patients with appendicitis. Similar studies have shown that older patients infrequently present with atypical findings and are four times less likely to mount a fever in response to an intra-abdominal infection than in younger patients.(61, 65) Use of CT has been increasing in this patient population and has been shown to improve the accuracy in diagnosing appendicitis in the elderly with abdominal pain, particularly in equivocal cases.(66) However, others have found that despite the increased use of CT scanning in elderly patients there is no difference in the amount of time from admission to operation, morbidity, mortality, or HLOS. In some patients, CT scans were done late in their hospital course which suggests that earlier consideration of the disease, earlier use of CT in patients with equivocal findings, and prompt surgical consultation are needed to avoid unnecessary delays in management. Elderly patients will always present more often at a more advanced stage of disease than their younger counterparts, and altering their natural course will be difficult. The most impact can be made in those patients presenting early in the course of their disease by considering appendicitis at their initial presentation to the hospital.

SUMMARY

Although appendectomy is the most commonly performed emergent abdominal operation, the presentation is frequently atypical making the diagnosis difficult and the treatment challenging. The diagnosis of appendicitis still remains a clinical one but can become complicated in certain groups of patients. Much caution and a high index of suspicion are needed in all patients, but in particular, the elderly, the pregnant, and the morbidly obese, as a missed diagnosis can result in more devastating consequences. A laparoscopic approach can be recommended for those who are well-trained, however OA is still acceptable if an adequate laparoscopic skill set does not exist or in suspected cases of gangrenous or perforated appendicitis.

Evidence-based treatment recommendations:

Non-operative management of appendiceal mass	1C
Laparoscopic approach to nonperforated appendicitis	1B
Laparoscopic approach in obesity	2C
CT is more accurate than US	1B

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47 Bariatric Surgery Complications

Terrence M Fullum and Patricia L Turner

A 49-year-old male with a body mass index (BMI) of 54 was electively admitted for a laparoscopic Roux en Y gastric bypass (RYGB). The patient completed a 6-month preoperative wellness (behavioral modification, nutrition, and fitness) program that resulted in a preoperative weight loss of 34 lbs. During that time the patient underwent clinical evaluations by cardiology, pulmonology, gastroenterology, and psychology services and was deemed safe to undergo the procedure. The patient's comorbidities included hypertension, Type 2 diabetes, obstructive sleep apnea (OSA), low back and joint pain, and gastroesophageal reflux disease (GERD). Medications included atenolol, glyburide, hydrochlorothiazide, amlodipine, metformin, and nexium.

The surgery was uneventful and was completed in 94 minutes. A preoperative antibiotic, Cephazolin, was given 30 minutes prior to incision. The patient also received 40 mg of low-molecular-weight heparin (emeparin) just prior to the start of the operation.

Postoperatively the patient did very well. On postoperative day 1 (POD 1) he underwent a water-soluble contrast swallowing study which was normal, and showed no evidence of obstruction or leak. He tolerated a clear liquid bariatric diet, was ambulating, and had stable vital signs. He was discharged home late in the afternoon of POD 1.

On POD 5 the patient developed a sudden onset of epigastric abdominal pain, nausea, and chills. He presented to the emergency department 6 h later when his symptoms failed to resolve. Initial vital signs included a temperature of 99.8°F, a blood pressure of 118/78 mmHg, a pulse rate of 122, and a respiratory rate of 30. His pulse oxygen saturation on room air was 91%.

The physical examination was negative except for the abdominal exam which revealed mottling around the incisions with what appeared to be early wound infections with drainage from all six port sites. The patient's abdomen was completely nontender and without peritoneal signs.

Initial laboratory tests included a complete blood count (CBC) with a differential, a comprehensive metabolic profile, and a urinalysis. All values were normal except for a white blood cell (WBC) count of 12.1 thous/mcl with six bands, and serum glucose of 120 mg/dl.

A computed tomography (CT) scan of the abdomen (Figure 47.1) was obtained which revealed a leak from the gastric pouch and air in the subcutaneous tissues adjacent to the incision sites. Contrast was seen exiting the abdominal cavity through one of the port sites (Figure 47.2).
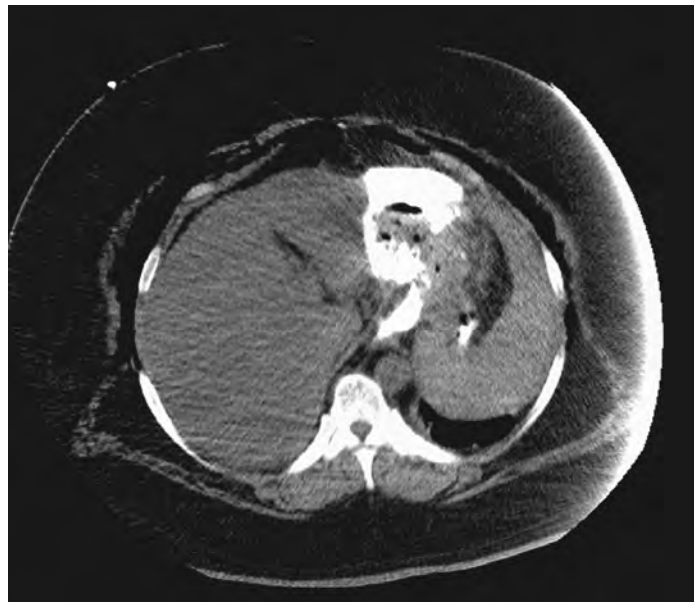
Figure 47.1 CT scan of the abdomen with contrast.

Figure 47.2 CT scan of the abdomen with contrast.

Two hours after reaching the emergency department (8 h after onset of symptoms) the patient was taken to the operating room. Preoperatively, the patient received levofloxacin and metronidazole. A diagnostic laparoscopy was performed and a 1.0-cm leak was identified proximally

Table 47.1 The International Classification of adult underweight, overweight, and obesity according to the BMI (Adapted from WHO 2004).

Classification	BMI (kg/m²)
Underweight	< 18.50
Severe	< 16.00
Moderate	16.00–16.99
Mild	17.00–18.49
Normal	18.50–24.99
Overweight	> 25.00
Pre-obese	25.00–29.99
Obese	> 30.00
Class I	30.00–34.99
Class II	35.00–39.99
Class III	> 40.00

along the gastric pouch staple line. There were no other intra-abdominal abnormalities other than approximately 500 cc of intra-abdominal gastric and intestinal fluid. The leak was repaired with 2-0 silk suture in a running fashion. The repair was leak-tested with methylene blue and air. The abdominal cavity was copiously irrigated and the epigastrium was drained with two active sump drains.

Following surgery, the patient developed sepsis with renal insufficiency and respiratory failure over the next 24 h, but subsequently recovered and was extubated on postoperative day 7. He was started on oral liquids after a negative water-soluble contrast upper GI series on postoperative day 10. Over the following 3 days, he was transitioned from parenteral to enteral nutrition, his antibiotics were discontinued, his drains were removed, and he was discharged home on postoperative day 14 in stable condition.

IMPORTANT ASPECTS OF THE EPIDEMIOLOGY OF MORBID OBESITY

The World Health Organization defines obesity by using the BMI (Table 47.1). The prevalence of adult obesity in the United States has increased from 12% in 1962 to over 50% in 2007.(1–4) There are 23 million people in the United States with a BMI > 35 kg/m² and 8 million with a BMI > 40 kg/m².(5) Moreover, childhood obesity rates tripled from 1980 to 2004, from 5 to 17%.(6) The United States is the only country in which the lowest socioeconomic class has the highest incidence of obesity.(7) The Healthcare Cost and Utility Project (7) reported that of the 20,771 gastric bypasses performed in 2000 in the United States, 81% of patients had commercial insurance, 5% had Medicare, 8% had Medicaid, and 4% were self-payers. The ethnic mix in these patients included 82% of whites, 9% of Latin ancestry, and 9% of blacks. The study reported that although 13% of patients undergoing gastric bypass had Medicare or Medicaid, 28% percent of the morbidly obese who qualified for the surgery had Medicare or Medicaid as their primary insurance.

The level of education is inversely proportional to the risk of obesity.(7) Fifty-four percent of the morbidly obese have a high school or General Educational Development (GED) diploma as their highest level of education. Only about half as many morbidly obese individuals have bachelor or doctorate degrees compared to the nonmorbidly obese. Thirty percent had an annual income of under $20,000.00.(7)

Obesity is not just an epidemic in the United States. Globally, the same number of people who are overweight (BMI > 25 kg/m²) match the same number of people who are starving at 2 billion.(8–10)

WHAT ARE THE POTENTIAL CONSEQUENCES OF MORBID OBESITY AND HOW IS IT AFFECTED BY DIETING?

The most commonly associated medical complications with morbid obesity include hypertension, Type 2 diabetes, hyperlipidemia, OSA, osteoarthritis, and venous insufficiency.(11)

Medically supervised diet and exercise programs are successful for a short term, but for the morbidly obese they are rarely successful, and most patients go through periods of weight loss and weight gain with a net effect of weight gain.(12) According to Atkinson (13), an optimal and continuous program that uses diet, medications, behavior modification, and exercise, can expect to achieve and maintain a weight loss of 10 kg (22 lbs) if continued permanently. The deleterious effects of the chronic medical complications of morbid obesity over many years may lead to end-organ failure, cancer, and a decreased life expectancy of up to 20 years.(14)

WHAT ARE THE PATIENT SELECTION CRITERIA FOR WEIGHT REDUCTION SURGERY?

In 1991, the National Institutes of Health (NIH) Consensus Conference (15) concluded that surgery was the only effective long-term treatment for patients with morbid obesity. The conference also established criteria for patient selection for surgery. In addition to BMI and comorbidity requirements, a documented history of multiple failed attempts at medical weight loss, an absence of psychiatric disorders, and cardiac and pulmonary medical risk evaluations were required to be in compliance. Saltzmann (16) and Shikora (17) also recommended behavioral and social assessments to identify patients who can comprehend and adjust to the life-changing effects of the surgery. The cardiac and pulmonary medical risk evaluations are to confirm that the comorbidities associated with the patient's morbid obesity do not create an unacceptably high operative risk.

WHAT ARE THE CONTRAINDICATIONS FOR WEIGHT REDUCTION SURGERY?

The medical, psychological, and social screening processes recommended by the NIH Consensus Panel (15), Saltzmann (16), Shikora (17), and others identify patients whose psychological and clinical diseases are severe enough to preclude surgical intervention. Herpetz (18) identified factors that are likely to increase the risk of inadequate weight loss or weight regain after surgery. DeMaria (19) developed a risk-scoring system that may aid in evaluating high-risk patients. Additional behavioral red flags that we have identified include noncompliance with medications and an unsupportive family environment. Clinical and behavioral concerns that may be contraindications for weight loss surgery are listed in Table 47.2.

Table 47.2 Contraindications for Surgery.

1. Significant psychiatric disorders or major depression
2. Severe mental retardation
3. Drug or alcohol abuse
4. Major organ failure
5. Behavioral red flags
    a. Abusive behavior toward office staff
    b. Repeated missed appointments
    c. Active tobacco abuse
    d. In a hurry to have surgery
    e. Significant weight-gain during preoperative process
    f. With-holding information or being untruthful
    g. Weight regain after previous bariatric surgery
    h. Non-compliance with medications
    i. Unsupportive family environment

WHAT ARE THE RISK FACTORS FOR WEIGHT REDUCTION SURGERY?

The preoperative assessment of the bariatric patient is critically important. Many patients may have had suboptimal healthcare and poorly managed comorbid diseases. Benotti (20) reviewed 1,210 consecutive patients and found that the total number of comorbid diseases was statistically associated with increasing age, increasing BMI, and male gender. These patients had increased comorbidity and thus were sicker patients at higher risk for surgery. Jamal (21) studied 1,465 patients who underwent bariatric surgery. Those with major comorbid diseases (hypertension, diabetes, OSA, venous stasis disease, pseudotumor cerebri, and obesity hypoventilation) had a higher BMI (35 ± 8 vs. 32 ± 6, $p < 0.001$), a higher mortality rate (2.3% vs. 0.2%, $p < 0.0032$), a greater leak rate (4.1% vs. 1.2%, $p < 0.0032$), and a higher rate of surgical site infection (3.9% vs. 1.4%, $p < 0.0133$).

It is the responsibility, therefore, of the bariatric team to recognize these diseases, improve or stabilize them prior to surgery, and to identify those patients who are at higher risk for postoperative complications.(19, 20–26) All preoperative evaluations should include a behavioral health assessment, cardiac evaluation, pulmonary evaluation to include pulmonary function tests with an arterial blood gas, a nocturnal polysonography, and an upper endoscopy. Hypertension and Type 2 diabetes should be tightly controlled prior to surgery. It is ironic that the patients at greatest risk, that is, the older super-obese male patients, patients with OSA, and patients with limited cardiopulmonary reserve, are those who may benefit most from surgical weight loss.

Derangements in pulmonary function are common in the morbidly obese.(27) These changes can result in hypoxemia and chronic hypercapnea. Postoperative lung volumes and pulmonary function are reduced by 50% after open bariatric surgery and by 40% after minimally invasive bariatric procedures.(27, 28) This can lead to significant hypoxemia in the immediate postoperative period in patients with severe preexisting reduction in pulmonary function. Identifying these patients preoperatively will facilitate respiratory care postextubation including the use of positive pressure ventilation which has been shown to reduce failed extubation after weight loss surgery in the immediate postoperative period.(29, 30)
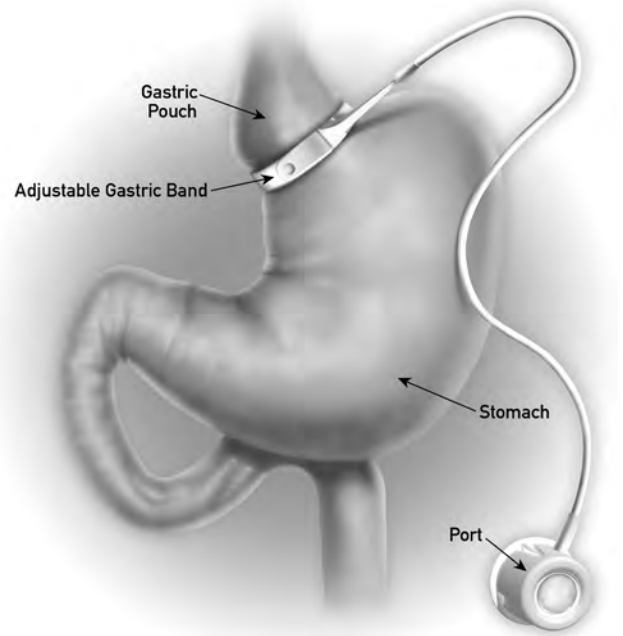
Figure 47.3 Adjustable gastric band.

Smoking is a proven risk factor for postoperative pulmonary complications including atelectasis and pneumonia, and should be stopped at least 8 weeks prior to surgery.(31) Benotti (25) recommended that preoperative weight loss strategies for high-risk bariatric surgery patients be a part of the plan for all programs. Modest (10–15%) weight loss in these patients may lower blood pressure, induce spontaneous diuresis, improve glycemic control, and reduce thrombosis risk. At our institution, all patients enter a preoperative "wellness" program that focuses on nutrition, fitness, life-style changes, and weight loss. This provides an assessment of the patient's willingness to modify behavior which may predict compliance and motivation in the postoperative period. Patients who gain weight during this period may not be considered for surgery until such time that appropriate behavior modification occurs.

WHAT ARE THE MOST COMMON TYPES OF WEIGHT LOSS SURGERIES?

Weight loss surgery falls into three main categories: (1) restrictive; (2) largely restrictive, mildly malabsorptive; and (3) largely malabsorptive, mildly restrictive. This chapter will be limited to the discussion of the most common procedure in each category.

Restrictive: Adjustable Gastric Band

A hollow silicone band is placed around the proximal stomach creating a small 20–30 cc gastric pouch (Figure 47.3). The band creates a small passage and delays the emptying of food into the remainder of the stomach causing a feeling of fullness. The band is connected to an injection port by a thin catheter. The injection port is placed above the anterior fascia of the rectus muscle for easy access. The band's tightness is adjusted by injecting saline into the band through the port. Adding saline narrows the stomach lumen which causes early satiety and restriction of food
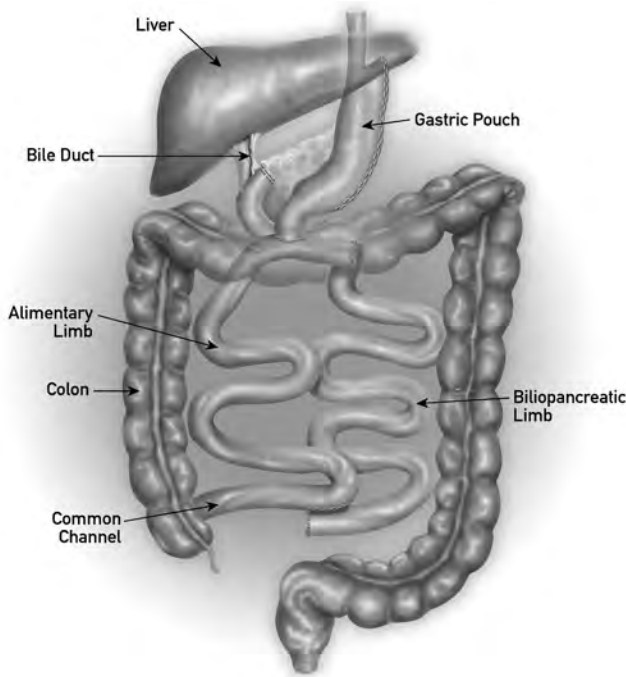
Figure 47.4 Biliopancreatic diversion.

Figure 47 5 Roux en Y gastric bypass.

intake. These purely restrictive gastric operations serve only to restrict and decrease food intake and do not interfere with the normal digestive process.

The band's tightness can be adjusted over time to provide more or less restriction to the stomach lumen. It may be necessary to tighten the band if weight loss is inadequate or to loosen the band if dysphagia results. Initially, the pouch holds about 1 ounce of food and later expands to 2–3 ounces.

Largely Restrictive, Mildly Malabsorptive:
Roux En Y Gastric Bypass

In most cases, a small 15–30 cc gastric pouch is created using a linear stapling device along the proximal part of the lesser curvature of the stomach (Figure 47.5). The jejunum is then transected about 45 cm distal to the ligament of treitz, and a jejunojejunostomy (JJ) is created between 75 and 150 cm distally. The resulting *Roux* limb is then brought in a retrocolic retrogastric or antecolic antegastric direction and is anastomosed to the gastric pouch using a circular or linear stapler. The goal is to create an anastomosis no larger than 1.5 cm in order to cause some restriction resulting in delay in emptying of the gastric pouch. This delayed emptying, in addition to decreases in the hormone ghrelin, leads to early satiety. The small 15–30 cc gastric pouch limits the amount of food intake. The *Roux* limb bypasses the remainder of the stomach, the duodenum, and the first 45 cm of jejunum, causing reduced calorie and nutrient absorption.

Largely Malapsorbtive, Mildly Restrictive:
Biliopancreatic Diversion/Duodenal Switch

The components of a biliopancreatic diversion include the creation of a sleeve-shaped gastric pouch that reduces the overall

Table 47.3 Reversal or Improvement After Weight-Loss Surgery.

1.	Hypertension
2.	Type 2 diabetes
3.	Hyperlipidemia
4.	Obstructive sleep apnea
5.	Congestive heart failure
6.	Urinary stress incontinence
7.	Asthma
8.	Weight-bearing joint and disk disease
9.	Gastroesophageal reflux disease
10.	Nonalcoholic fatty liver disease and cirrhosis
11.	Polycystic ovarian syndrome
12.	Pseudotumor cerebri
13.	Depression
14.	Intertriginous dermatitis

size of the stomach by 60% (Figure 47.4). The remainder of the stomach is resected and the duodenum is oversewn. The stomach is then anastomosed to the mid-jejunum, and the distal end of the biliopancreatic limb is attached to the ileum approximately 100 cm proximal to the cecum. Bypassing all but the distal ileum ensures that far fewer calories are absorbed. Malabsorption occurs as a result of increased gastric emptying rates and decreased intestinal transit times. In a biliopancreatic diversion with duodenal switch, the gastric sleeve is continuous with the first portion of the duodenum, which is anastomosed to the mid-jejunum. The duodenal switch was devised to allow normal filling and delayed physiologic emptying of the gastric sleeve through the pylorus which causes early satiety. In theory, along with the decreased parietal cell mass in the gastric sleeve, a functional pylorus was felt to decrease the incidence of marginal ulceration.(32–34)

Table 47.4 Review and Meta-Analysis of 136 Studies (*n* = 22,094 *patients*).

Results:	
% excess weight loss	61.2%
Operative (< 30days) mortality	0.1–1.1%
Resolution of diabetes	76.8%
Resolution of hyperlipidemia	79.3%
Resolution of hypertension	61.7%
Resolution of OSA	85.7%

WHAT ARE THE EXPECTED OUTCOMES AFTER WEIGHT REDUCTION SURGERY?

Successful weight loss after weight reduction surgery includes a greater than 50% excess weight loss (EWL) and improvement or resolution of associated comorbidities. Buchwald (35) reviewed the comorbidities reversed or improved by bariatric surgery (Table 47.3). He also showed that bariatric surgery improves quality of life, body image, personal hygiene, sexual function, employment, income, and job or professional advancement.(35) Buchwald's (36) meta-analysis of 22,094 patients reviewed EWL and resolution of four major comorbidities associated with morbid obesity following weight loss surgery (Table 47.4).

WHAT ARE COMMON COMPLICATIONS AFTER ROUX EN Y GASTRIC BYPASS?

Bleeding

Bleeding complications occur in up to 4% of patients after RYGB. (37) Common sites for bleeding include the mesentery, omental vessels, staple lines, short gastric vessels, spleen, liver, and the anterior abdominal wall port sites. The bleeding may be self-limited without clinical evidence or with only a small decrease in the hemoglobin and hematocrit. Bleeding that causes a significant drop in the hemoglobin and hematocrit or hemodynamic changes should be investigated and treated expeditiously. Intraluminal bleeding from the gastrojejunostomy or along the gastric pouch staple line may present with hematemesis, hematochezia, or melena. Bleeding from the JJ usually presents with hematochezia or melena. Suspected intraluminal bleeding from the gastric pouch or JJ can usually be diagnosed and treated with flexible endoscopy. Suspected intraabdominal bleeding in a stable patient may be confirmed via CT scan, but strong consideration should be given to exploration in all patients with postoperative intra-abdominal bleeding, and exploration is mandatory in patients with multiple transfusion requirements or hemodynamic instability.(37)

Anastomotic and Staple Line Leaks

Anastomotic and staple line leaks (ASLs) after RYGB occur in up to 6% of cases.(38–45) Most leaks occur along the gastric pouch staple line, the gastrojejunostomy, or the gastric remnant staple line. Leaks that occur in the first 24–48 h are usually due to technical or mechanical error. Most leaks occur between POD 3–7 and are most likely due to ischemic perforations at the gastrojejunostomy or along the gastric pouch staple line.

In a recent series of more than 3,000 gastric bypasses from four centers, the ASL rate was 2.1%.(46) The most common signs and symptoms of a leak were tachycardia (72%), fever (63%), and abdominal pain (54%). It is important to note that an upper gastrointestinal (GI) series was positive in only 17 of 56 patients with leaks (30%) and computed tomography was positive in 28 of 50 patients with leaks (56%). Both studies were negative in 30% of patients with leaks.

It is important to understand that this complication may present with subtle findings.(46) Physical examination findings of peritonitis in the obese are often difficult to elicit and tachycardia, tachypnea, decreasing oxygen saturation, or decreased urine output may be the only early signs. Patients who have normal pulse rates in the preoperative and early postoperative period, who acutely develop tachycardia, particularly rates above 120 beats/min, should be evaluated for leaks. It should also be noted that patients on beta blockers may not manifest tachycardia in spite of an ASL.

Small contained leaks in which most of the contrast remains intraluminal and passes into the lower GI tract, in stable patients, can often be successfully treated with percutaneous drainage, intravenous (IV) antibiotics, and total parental nutrition (TPN).(44, 46)

Large leaks and small leaks in unstable patients should undergo immediate operative repair with wide drainage of the area, IV antibiotics, and TPN or distal enteral feeding. Laparoscopy is appropriate for the stable patient, but unstable patients should undergo an open exploration.(44, 46)

Surgeons should maintain a low threshold for abdominal exploration in a post–weight loss surgery patient who develops a sudden onset of tachycardia but has negative radiologic tests even if the patient looks and feels well.(46) Delays in treatment of a leak may lead to sepsis and multiple organ failure. Mortality rates can approach 50% in such cases.(47) On the other hand, a negative exploratory laparoscopy has minimal morbidity and mortality.

Wound Complications

The laparoscopic approach has resulted in a decreased incidence of wound infections compared to the open technique. Podnos (37) reported wound infection rates of 2.9% after laparoscopic and 6.6% after open RYGB (*p* < 0.001). The laparoscopic approach eliminates the risk of wound dehiscence or evisceration and port-site infections are typically easy to manage with open drainage and antibiotics when appropriate.

Venous Thromboembolism

Any post–weight loss surgery patient who presents with shortness of breath and hypoxemia should be evaluated for pulmonary embolism.

Increasing BMI is predictive of higher venous thromboembolism (VTE) rates in patients undergoing abdominal operations. (48) Obesity and the metabolic syndrome are associated with a procoagulant state with elevated levels of fibrinogen, factor VII, factor VIII, von Willebrand factor, and plasminogen activator inhibitor.(49) Currently, there are no studies demonstrating a difference in VTE rates between the laparoscopic and open approaches in patients undergoing Roux en Y gastric bypass.

It is recommended that sequential compression devices, early ambulation, and some form of low-dose unfractionated heparin or low-molecular-weight heparin be used perioperatively in bariatric surgery patients.(49)

Preoperative placement of inferior vena cava filters should be considered in patients at high risk for thromboembolic events. This category includes patients with a history of VTE/PE, venous stasis disease, or obesity hypoventilation syndrome; patients with a BMI of 60 or more; or patients with a known hypercoagulable state.(50, 51)

Management of VTE/PE is the same in the bariatric surgery patient as any other postoperative patient including full anticoagulation.

Anastomotic Strictures

The 2–20% incidence of anastomotic stricture at the gastrojejunostomy is directly related to surgeon's experience and the technique used to create the anastomosis.(37) Hand-sewn anastomoses have the lowest rate, followed by the linear stapler, and the highest rates occur with the circular stapler technique. Most series, regardless of technique, report stricture rates of less than 7%.(39–45, 52–54)

The most common presentation of an anastomotic stricture is progressive nausea and vomiting to solids and liquids in the first 3 months after surgery.(52) Anastomotic strictrures that are associated with marginal ulcers may be accompanied by epigastric pain and may occur at any time in the postoperative period.

The diagnosis of stricture is confirmed by flexible endoscopy and the majority of strictures (85%) can be managed with endoscopic dilation.(52) Occasionally, a stricture will require stenting or operative revision.

Marginal Ulcers

Marginal ulcers occur at the gastrojejunostomy, usually on the jejunal side, and may be associated with bleeding, anastomotic strictures, or gastro-gastric fistulae. Suspected causes include ischemia, tension on the anastomosis, nonabsorbable sutures and staples, nonsteroidal anti-inflammatory drug (NSAID) use, excessive acid exposure in the gastric pouch as occurs with a gastro-gastric fistula, and smoking.(39, 44, 54–56)

The incidence of marginal ulcers after laparoscopic RYGB ranges 0.5–5%.(39, 44, 54–56) The most common clinical presentation is epigastric pain, vomiting, and anemia. Treatment includes long-term acid suppression therapy and removal of nonabsorbable sutures when present. Rarely, anastomotic revision is required for intractable ulcers.

Bowel Obstruction

Small bowel obstruction after gastric bypass can occur from adhesions, ventral hernias, stricture at the JJ, or internal hernias. Most large series report bowel obstruction rates up to 10.5%.(44, 54–59) Bowel obstruction from adhesions and ventral hernias occur less frequently following the laparoscopic approach.

Internal Hernias

Internal hernias can occur through the mesenteric defect of the JJ, between the transverse colon and the *Roux* limb, or through the mesocolon defect with retrocolic *Roux* limbs. All mesenteric defects should be closed with permanent suture to reduce the incidence of internal hernias. Signs and symptoms of an internal hernia may be subtle. Patients may present months or years postoperatively with crampy intermittent abdominal pain.

Diagnostic studies for internal hernias may include abdominal CT scan (60) looking for the diagnostic "mesenteric swirl" or an upper GI series with a small bowel follow-through looking for signs of small bowel obstruction. Because the hard findings of internal hernia are so subtle, and because missing the diagnoses carries a significant risk of intestinal necrosis, symptomatic patients with negative studies should undergo diagnostic laparoscopic or open exploration to evaluate for an internal hernia.(61)

Nutritional Deficiencies and Polyneuropathies

Vitamin and protein deficiencies occur because the stomach, duodenum, and part of the jejunum are bypassed during a standard RYGB. The incidence and prevalence of these deficiencies are unknown, but will occur if patients do not receive supplementation. Although supplement regimens vary among surgeons, most agree that patients should receive additional iron, vitamin B_1 (thiamine), vitamin B_{12} (cyanocobalamin), calcium, and vitamin D.(62) Surveillance protocols for deficiencies and patient compliance vary greatly, although most bariatric surgeons recommend annual serum testing.

Acquired deficiencies in thiamine and cyanocobalamin cause the most common post-bariatric-surgery polyneuropathies (BSP). (63–69) Thiamine deficiency may present as neurologic beriberi or wet beriberi. Neurologic beriberi describes a peripheral neuropathy that progresses to Wernicke's encephalopathy which is characterized by confusion, ataxia, and opthalmoplegia**.** Wet beriberi manifests as heart failure or as a myocardial infarction leading to death within hours. Presenting symptoms include ataxia, loss of pain sense and a "stocking glove" paresthesia. Confusion or Korsakoff psychosis, an irreversible finding associated with thiamine deficiency, is characterized by confabulations, and retrograde and antegrade amnesia.

Cyanocobalamin deficiency results from a decreased exposure to intrinsic factor which is located in the bypassed stomach remnant. As a result, crystalline vitamin B_{12} is inadequately absorbed in the terminal ileum. Presenting symptoms of this deficiency include spasticity, poor position and vibration sense, and decreased proprioception.

Calcium and vitamin D absorption are impaired after RYGB and can lead to deficiencies in up to 10% and 51% of cases, respectively.(62) If not treated, these deficiencies can lead to secondary hyperparathyroidism and can result in increased bone turnover and decreased bone mass.

WHAT ARE THE COMPLICATIONS AFTER ADJUSTABLE GASTRIC BANDING?

The adjustable gastric band (AGB) was developed by Kuzmak (70) in 1986. This is considered to be the least invasive bariatric procedure because there is no creation of a staple line or disruption of the GI tract. A small pouch is created by placing an adjustable band around the proximal portion of the stomach. The laparoscopic approach led to a reduction in wound complications and pain, and allowed for a faster recovery.(71, 72)

Morino (73), in a prospective randomized trial, demonstrated that early morbidity was greater for vertical banded gastroplasty (VBG) than the adjustable gastric band (9.8% vs. 6.1%). However, AGB had more overall complications than VBG (32.7% vs. 9.8%) and there were more reoperations for AGB, mostly related to severe esophagitis, reflux disease, band slippage, and poor dietary compliance.

Complications of the Laparoscopic adjustable gastric banding (LAGB) include gastric perforation, port-site infection, band slippage, band prolapse, and band erosion.

Gastric Perforation

Gastric or esophageal perforation during surgical placement of the AGB is a rare but potentially life-threatening complication that may not be detected at the time of surgery. Signs and symptoms may consist initially of only tachycardia and low urine output.(74, 75) Subsequently, patients may develop abdominal or chest pain, fever, or shock. Diagnosis is confirmed by a water-soluble contrast upper GI swallow study or CT scan of the chest and abdomen. Treatment consists of reoperation, removal of the AGB, primary repair of the perforation, drainage, IV antibiotics, and a feeding gastrostomy or jejunostomy.

Port-Site Infection

The incidence of infection at the injection port-site is 0.4–1.0%. (76–79) Erythema, induration, tenderness, and drainage at the port-site should be treated with deflation of the balloon, laparoscopic disconnection of the catheter from the band, and removal of the catheter and port. Local wound care and antibiotics should be administered until the infection has resolved. A band erosion should be ruled out via endoscopy. Once all signs of infection are gone a new port and catheter can be re-connected to the band from a different abdominal wall site.(76)

Band Slippage

Band slippage changes the orientation of the band with respect to the proximal part of the stomach and results in an enlarged proximal gastric pouch and partial obstruction. The incidence ranges 2.3–12.5%.(76–83) The most common sign is vomiting after eating. The incidence of band slippage has been reduced since placement of anterior gastro-gastric fixation sutures around the band has become more common.(78)

Prolapse

Prolapse of the stomach through the band can occur anteriorly, posteriorly, or symmetrically. Symptoms include dyphagia, reflux, regurgitation, and progressive food intolerance. The diagnosis is made with an upper GI series or endoscopy. Initial treatment is to deflate the band, and this may suffice for a small prolapse. More commonly, however, surgical correction is necessary to reduce the prolapse, replace or reposition the band, and to place gastro-gastric fixation sutures. Prolapse may be related to surgeon experience as Obrien and Dixon reported a 25% prolapse rate in their first 500 patients and a 4.7% prolapse rate in their last 600 patients.(84)

Band Erosion

Band erosion is an infrequent, late complication that may be related to an overtight anterior plication or plication of the stomach over the buckle of the band.(85) The incidence ranges 0.1–2.8%.(76–83) Signs and symptoms include abdominal pain, weight regain, loss of the sensation of early satiety, port-site infections, and reflux. Diagnosis is made endoscopically and treatment consists of surgical removal of the band, suture closure of the perforation, drainage, and intravenous antibiotics.(76) Occasionally, a feeding gastrostomy or jejunostomy may be required.

WHAT ARE THE COMPLICATIONS AFTER MALABSORPTIVE PROCEDURES?

Biliopancreatic diversion with or without duodenal switch is considerably more complex and technically more difficult than the other forms of weight loss procedures. It is performed in only a few centers and comprises less than 1% of all weight loss surgeries performed. It is usually reserved for super-obese patients or patients who have failed to respond to other forms of weight loss surgery.

Biliopancreatic diversion with or without duodenal switch may be associated with higher mortality (1.1%) than other bariatric procedures.(34, 36, 62, 86–89) Operative complications were similar between laparoscopic and open groups, but were found to be higher in super-super-obese patients (BMI> 60 kg/m^2).(34, 90, 91) The most prevalent surgical complications include incisional hernias (18%) and anastomotic ulcers (6.3–10.6%). Long-term nutritional deficiences can occur in up to 40% of cases. (62, 88, 89) Nutritional complications include anemia, protein-calorie deficiences, vitamin B$_{12}$ deficiency, hypocalcemia, fat-soluble vitamin deficiency, and bone demineralization. Reduction in operative complications decrease with the experience of the surgeon, (87) and nutritional complications can be reduced or avoided with close follow-up and long-term vitamin and protein supplementation.(62)

WHAT IS THE MORTALITY AFTER WEIGHT LOSS SURGERY?

A report by the Agency for Healthcare Research and Quality released in January 2007 concluded that the inpatient mortality rates for all weight loss surgery procedures decreased by 78% between 1998 and 2004, that is, 0.89–0.19%.(89)

A meta-analysis by Buckwald (36) on 22,094 patients in 136 studies on all types of open and laparoscopic procedures, revealed a 30-day mortality rate for RYGB of 0.5% and 1.1% for BPD and BPD/DS, respectively.

Chapman (92) reviewed the international literature and reported operative mortality rates of 0.05% for LAGB and 0.5% for RYGB.

WHAT SHOULD EVERY ACUTE CARE SURGEON KNOW ABOUT THE EMERGENCY ROOM EVALUATION OF THE POST–WEIGHT LOSS SURGERY PATIENT?

As the number of weight loss surgical procedures increases each year, more patients will present to their local emergency departments for evaluation and treatment of postoperative complications.

Effective acute evaluation and treatment of the post–weight loss surgery patient requires that the hospital be prepared to accommodate the morbidly obese. It is necessary to have beds and wheel chairs large enough to hold and transport these patients. Properly sized blood pressure cuffs, oxygen saturation monitors, and CT scan and fluoroscopy tables are necessary to obtain accurate information that will allow definitive care in a timely manner.

The surgical team will be primarily responsible for evaluating these patients. However, a multidisciplinary approach which includes emergency physicians, radiologists, and gastroenterologists is often necessary to provide the appropriate care. These clinicians should be familiar with the most commonly performed weight loss procedures and their potential complications.(93–97)

ASLs, thromboembolism, and respirator failure are the most common causes of mortality in the post–weight loss surgery patient.(97) With ASL and thromboembolism, delay in definitive care is directly related to increased morbidity and mortality. ASLs usually occur within 7 days after surgery, but a thromboembolic event can occur anytime in the postoperative period. Other common complications that occur early include GI bleeding, dehydration, and infection (wound, urine, pulmonary, intra-abdominal). Late (after 30 days) complications include marginal ulcer with or without perforation, anastomotic stricture, gastro-gastric fistula, bowel obstruction, nutritional deficiencies and polyneuropathies.

Macronutrient deficiencies include severe protein-calorie malnutrition and fat malabsorption.(98) The most common micronutrient deficiencies are of vitamin B_{12}, iron, calcium, and vitamin D.(98) Other micronutrient deficiencies that may lead to polyneuropathies and other serious complications including thiamine, folate, and the fat-soluble vitamin deficiencies. Counseling, monitoring, and nutrient and mineral supplementation are essential for the treatment and prevention of nutritional and metabolic complications after bariatric surgery.(98)

Initial emergency room treatment for post–weight loss surgery patients should incorporate a rapid triage, and early evaluation to minimize the time to surgical intervention if needed. Many patients will present dehydrated and require IV hydration. Supplemental oxygen may be required for patients with OSA and oxygen desaturation. Insertion of a nasogastric tube should be avoided to eliminate the risk of traumatic perforation of the gastric pouch. Common serologic tests may include a CBC with differential, a comprehensive metabolic profile, amylase, lipase, serum lactate, arterial blood gas, and urinalysis. Information provided by these tests may support the diagnoses of dehydration, sepsis, pancreatitis, ASL, thromboembolism, or bowel ischemia. Patients who present greater than 30 days after weight loss surgery should have additional serologic tests for vitamins B_1, B_6, B_{12}, and vitamin D levels.

Radiographic diagnostic studies may include a CT scan of the abdomen or water-soluble upper GI series to evaluate for an ASL, anastomotic stricture, intra-abdominal abscess, or bowel obstruction. (99) A CT scan angiography of the chest should be ordered if there is suspicion of a thromboembolism. Upper endoscopy may be required in patients suspected of having staple line bleeding, a marginal ulcer, or a gastro-gastric fistula.

Urgent abdominal exploration should be considered in any patient with bowel obstruction, massive GI bleeding, or ASL.

It is important to not underestimate the potential life-threatening complications in any post–weight loss surgery patient who presents with minimal signs and symptoms. Diagnosis made during this "golden period" will often minimize the patient's overall morbidity and mortality. It is far better to work the patient up and find only dehydration than to be swayed by the patient's apparent "healthy" status only to watch the patient deteriorate over time.

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48 Diverticulitis
Carrie Allison, Daniel Herzig, and Robert Martindale

A 40-year-old man with a history of diverticulitis presents with several days of constipation, left lower quadrant pain, fever, chills, temperature to 38.5°C and leukocyte count of 13,000. Computed tomography (CT) reveals diverticulitis with pericolonic stranding and no evidence of abscess or perforation. He is treated with bowel rest and broad-spectrum antibiotics. He improves and is discharged home on hospital day 4. Two years later the patient returns with similar symptoms. CT shows pericolonic stranding and free air. At operation, the patient is found to have free perforation with minimal fecal contamination. A sigmoid colectomy with primary anastomosis is performed. On postoperative day (POD) 5, the patient develops tachycardia, hypotension, fever to 39°C and diffuse peritonitis. The patient is taken back to the operating room for exploration where an anastomotic leak is identified. Hartmann's procedure with end colostomy is performed. Over the next week, the patient recovers slowly and is ultimately discharged on POD 12.

INTRODUCTION

Diverticulosis and diverticulitis together represent a spectrum of pathology commonly referred to as *diverticular disease.* Presentations of this disease range from an asymptomatic state to life-threatening acute intra-abdominal sepsis. We will first discuss the epidemiology and natural history of the disease, followed by a discussion of the evaluation and management of the four types of diverticulitis: acute uncomplicated, chronic and recurrent uncomplicated, acute complicated, and chronic complicated. Particular attention will be paid to the controversies that exist in the management of this common disease, including timing and indications for elective surgery in recurrent disease, type and timing of staged operations in complicated disease, and the management of disease in the young.

DIVERTICULITIS: BACKGROUND AND EPIDEMIOLOGY

Diverticulosis is an increasingly common disease of industrialized culture.(1, 2) Pathologically, it is characterized by multiple small outpouchings, or diverticula, within the colon. These false or pulsion diverticula are formed by small herniations of mucosa and submucosa through the muscularis layer, projecting through natural weak spots along the sites of penetration of the vasa recta. While diverticula may appear anywhere throughout the colon, the sigmoid colon is the most commonly affected location, involved in 95% of cases. Thirty-five percent of patients will also demonstrate proximal colon involvement.(3–5) Diverticulitis is seen equally in women and men.(1)

Predominance of diverticula in the right colon is rare, seen more commonly in Asian populations, and may represent a congenital process.(6–8)Acute right-sided diverticulitis is commonly confused with appendicitis. Its treatment is controversial. A recent retrospective series by Yang et al. in 2006 (9) of 113 patients over 10 years showed a range of successful treatment strategies including conservative management (50%), diverticulectomy (7%), appendectomy (28%), and right hemicolectomy (15%).

What Causes Diverticulosis?

Early in the 20th century, diverticula were uncommonly observed in autopsy series, at rates of 5–10%.(2, 10) However, by 1969, this number increased to 55% of autopsies.(11, 12) While it is difficult to determine exactly, currently it is estimated that 5–10% of people by age 40 and 70–80% of people by age 80 will develop diverticulosis.(13, 14) This change in prevalence in diverticulosis has been attributed to a change in the dietary habits of industrialized Western society to include more red meat, highly processed grains, and fewer fruits and vegetables. British physicians Burkitt and Painter first postulated a low-fiber diet as an etiology for the development of diverticulitis while working in Africa, noticing that native Africans eating diets high in plant fiber and low in red meat had bulkier, softer stools and shorter stool transit time than their Western counterparts.(2, 5, 15) Burkitt and Painter observed that the Africans rarely developed diverticulitis while it was an increasingly common affliction of their Westerner counterparts.

The epidemiologic data supporting a low-fiber diet as the primary etiology for the development of diverticulosis has been further supported by large modern cohort and case-control studies.(16, 17) Diets low in fiber create smaller stools that require higher pressure, leading to herniation through weak areas in the colonic walls in the relatively narrow sigmoid colon.(5, 18, 19) Changes in colonic wall content of collagen and elastin seen with aging may also play a role.(20)

How Does Diverticulosis Progress to Diverticulitis?

Diverticulosis becomes symptomatic and pathologic when diverticula become inflamed or perforated. While the etiology for the development of diverticulosis is well accepted, the inciting factors for the progression to diverticulitis remain somewhat a mystery. Traditionally, it has been postulated that diverticulitis is caused by inspissated feces or food particles, leading to perforation of the diverticulum. Current theories suggest that a low-fiber diet leads to alterations in colonic microflora and a suppressed local immune response that may predispose to chronic or acute inflammation, leading ultimately to microperforation.(21–23)

Risk factors for the development of diverticulitis besides advancing age include a diet low in plant fibers and high in red meats and processed grains.(16, 17) Nonsterioidal anti-inflammatory drugs, opiates, smoking, and immunocompromise may increase the likelihoood of developing complicated diverticulitis.(24–30)
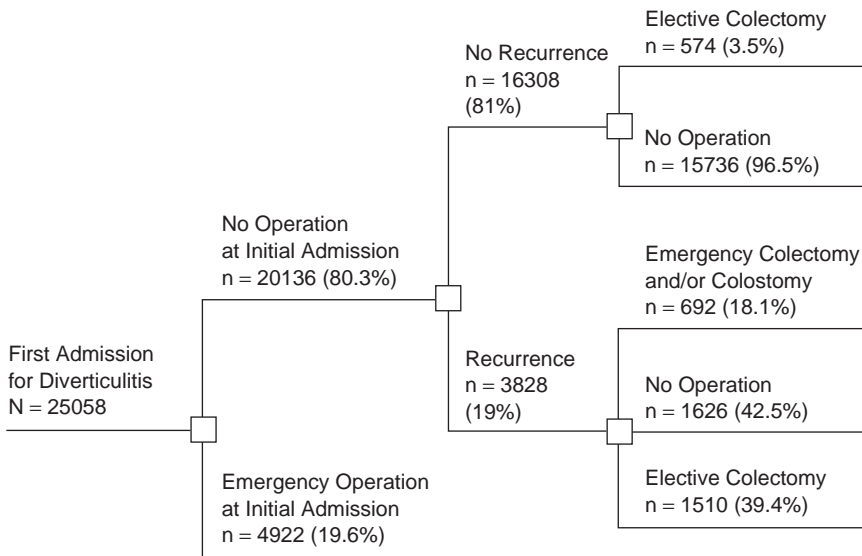
Figure 48.1* Natural history of patients hospitalized for diverticulitis.

*Reproduced with permission from Anaya et al. Arch Surg 2005; 140(7): 681–5.

NATURAL HISTORY OF DIVERTICULAR DISEASE

As many as 70–80% of the population will develop diverticulosis by age 80. The vast majority of those will remain asymptomatic. It is estimated that fewer than 1% of patients with diverticulosis will ultimately require operative intervention.(31) However, 10–25% of patients with diverticulosis will develop an episode of diverticulitis at some point in their lifetime.(14, 32) Many will be managed as outpatients. Of those hospitalized with a first episode of diverticulitis, 20% will undergo emergent operation (Figure 48.1). The remaining patients will develop a second episode 30% of the time, and similarly 30% of those patients will develop a third.(14, 32, 33) Of those who recur, 18% will undergo emergency operation, similar to the rates of operation at first admission.(34)

Diverticulitis is characterized by being complicated or uncomplicated, acute, chronic, or recurrent. Pathology occurs when a diverticulum perforates, either in contained fashion or freely within the peritoneal cavity. The anatomic location and size of the perforation determine the disease presentation. Perforation may be small and contained, leading to intramesenteric abscess or phlegmon. Alternatively, larger remote abscesses or free perforation of either pus or feces may occur. The Modified Hinchey Classification system (35, 36) (Table 48.1) describes findings associated with perforation.

EVALUATION OF DIVERTICULAR DISEASE

Patients suspected to have diverticulitis should undergo a complete evaluation starting with a full history and physical exam. Signs and symptoms suggestive of diverticulitis include left lower quadrant pain, abdominal cramping, diarrhea, constipation, and fevers. Laboratory evaluation should include a complete blood count, blood urea nitrogen (BUN), creatinine, and urinalysis. Uncomplicated disease, particularly in a patient with a history of diverticulitis, is often diagnosed on history and physical exam alone.

Patients with more severe disease such as diffuse peritonitis or systemic signs of illness should undergo radiographic evaluation.

Table 48.1 Modified Hinchey Classification of Diverticulitis*.

I	Pericolic abscess
IIa	Distant abscess amenable to percutaneous drainage
IIb	Complex abscess with/without fistula
III	Purulent peritonitis, noncommunicating with bowel lumen
IV	Fecal peritonitis, communicating with bowel lumen

*Adv Surg 1978; 12: 85–109. Surg Endosc 1997; 11(3): 264–7.

Barium enema was historically used, however, this modality has limited specificity and cannot be used for radiologic planning for percutaneous abscess drainage.(33, 37) Currently, CT of the abdomen and pelvis with intravenous (IV), oral, and rectal contrast is the diagnostic tool of choice with sensitivity, specificity, and accuracy of 97–98%.(33, 38) While endoscopic evaluation has limited use in the acute setting, all patients without a recent evaluation of the colon should have a full colonoscopy 6 weeks after resolution of the acute attack.(39)

ACUTE UNCOMPLICATED DIVERTICULITIS

Acute uncomplicated diverticulitis is typically characterized by acute onset left lower quadrant pain, and variably, mild fever, leukocytosis, diarrhea, or constipation. Physical examination may show localized tenderness with voluntary guarding or other signs of focal peritonitis. Pathologically, microperforation with containment of the infectious and inflammatory process within the colonic mesentery, retroperitoneum, or pericolonic tissue is observed, resulting in localized inflammation. CT will demonstrate focal areas of inflammation with bowel wall thickening and mesenteric fat stranding.

Treatment of acute uncomplicated diverticulitis is initially nonoperative, and medical management alone is successful in over 70% of patients. Three criteria are generally used to select patients who might succeed with outpatient management: (1) ability to tolerate oral intake; (2) the absence of systemic signs of illness such as fever, tachycardia, and leukocytosis; and (3) the
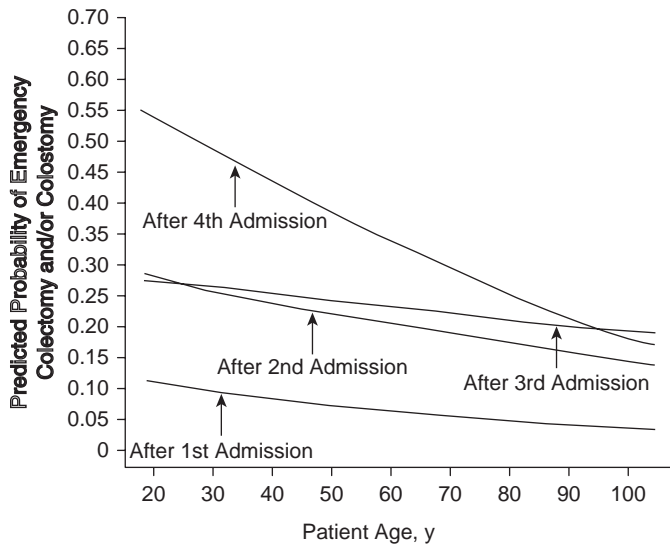
Figure 48.2* Probability of adverse outcome by number of admissions.

*Reproduced with permission from Anaya et al. Arch Surg 2005; 140(7): 681–5.

absence of localized peritonitis. Mainstays of treatment include bowel rest or clear liquids initially, with gradual advancement to a restricted, typically low-fiber diet until symptom resolution. (39) According to Surgical Infection Society guidelines, single or multiagent antibiotic regimens in IV or oral form should be administered for no more than five to 7 days, and may be discontinued after resolution of fever and leukocytosis.(40) The most commonly involved organisms include *Escherichia coli*, *Streptococcus* species, and anaerobes. Single drug (e.g., piperacillin/tazobactam, carbapenems, or second generation cephalosporins) or combination agents (e.g., fluroquinolone or third generation cephalosporin with metronidazole or clindamycin) active against these bacteria are equally effective.(41) Failure of improvement in leukocyte count and/or defervescence at 48 h after admission is predictive of requiring either a prolonged hospital course or surgery.(42) The vast majority of these patients will not develop recurrent diverticulitis.(14, 32, 33) After resolution of an acute attack, dietary fiber supplementation may decrease the likelihood of recurrence.

RECURRENT UNCOMPLICATED DIVERTICULITIS

When Should Elective Resection Be Performed After Recurrent Episodes of Uncomplicated Diverticulitis?

Perhaps the greatest controversy in the management of diverticulitis lies in the treatment of recurrent uncomplicated disease. Previous guidelines suggested that elective resection should be performed after two episodes of acute uncomplicated diverticulitis. The goal of elective surgery was to prevent an episode of complicated diverticulitis with its high attendant mortality and the possibility of a colostomy. However, these guidelines were based on outcomes from data generated in the 1960s.(3) Treatment of diverticulitis has changed significantly in recent years with the advent of better antibiotics, imaging technology, and interventional techniques. In

2005, Chapman et al. retrospectively studied 337 patients admitted for complicated diverticulitis and found mortality of ≤ 1% associated with all presentations of complicated disease with the exception of free perforation, which carried 12% mortality. The majority of patients who presented with free perforation had no history of previous attacks.(43) These authors propose that immunosuppression and advanced age are more important than number of recurrences for predicting the development of complicated disease.

Given that sigmoid colectomy in the elective setting carries a mortality of 2–4%, it is questionable whether patients with recurrent disease will obtain overall better outcomes with prophylactic elective colectomy. Anaya et al. in 2005 investigated whether the number of episodes of recurrent diverticulitis increases the likelihood of ultimately requiring emergency colectomy. Particularly for younger patients, the risk of ultimately needing emergency colectomy dramatically increased only after the fourth hospital admission for acute diverticulitis (Figure 48.2).(34) Thus, it may not be prudent to recommend elective operation after only two attacks of acute diverticulitis. Current American Society of Colon and Rectal Surgeons guidelines state that recommendations for elective sigmoid colectomy should be made on a case-by-case basis.(39) While the number of previous attacks is not strongly predictive of the need for future emergent surgery, the CT graded severity of the first attack does correlate with severity of disease progression and may help determine whether elective operation is appropriate.(44)

Should I Alter the Management of Recurrent Disease in Young or Immunosuppressed Patients?

Two patient populations deserve special mention when considering elective colectomy after resolution of acute uncomplicated diverticulitis: young and immunosuppressed patients. Anecdotal experience has suggested that disease in patients < 50 years may follow a more severe course with a higher chance of complications compared to those presenting with their first episodes later in life. Guidelines in this patient population have previously been to recommend elective resection after the first episode of diverticulitis. However, there are only a few data supporting this recommendation, and there is no consensus whether disease in this population is truly more virulent or simply reflects a time bias with more years of life exposed to the disease.(14, 45–47) Because the risk of elective resection in this patient population is low, many patients will likely benefit from resection, but recommendations should be individualized.(45)

Patients with immunosuppression due to cancer, treatment of inflammatory diseases or in association with organ transplantation represent a population at particularly high risk for complications of diverticulitis. Signs of complicated disease such as diffuse peritonitis, fever, and leukocytosis may be attenuated or absent. This group is more likely to present with perforation and to die of complicated disease than immunocompetent patients.(43, 48) Thus, resection after an initial episode of uncomplicated diverticulitis may be appropriate in this group of patients.

What Is "Symptomatic Disease" and How Do I Treat It?

Chronic diverticulitis or "symptomatic disease" is characterized by either failure of resolution of symptoms from a primary episode

of diverticulitis, or recurrent episodes of left lower quadrant pain without systemic signs of illness. These symptoms are often worsened after eating, and relieved after defecation. Several strategies have been employed to attempt to reduce symptoms and to lengthen time between attacks. Preliminary studies using probiotics with or without mesalamine (49, 50) have shown some promise in reducing severity of symptoms and duration of remission, although more study is needed. Dietary fiber supplementation may help prevent subsequent attacks of diverticulitis, but has limited use for symptomatic control in chronic disease.(17, 51, 52) The fact that many of these patients respond to drugs such as mesalamine suggests a possible overlap between diverticulitis and inflammatory bowel disease.

Despite the finding that the pathology of resected specimens frequently demonstrate no active disease after resection for chronic symptomatic disease (53–55), the majority of these patients will experience complete resolution of their symptoms after elective sigmoid colectomy. Morbidity and mortality associated with elective sigmoid colectomy in this group is very low.(56) Thus surgery remains a viable option for patients with refractory symptoms.

ACUTE COMPLICATED DIVERTICULITIS: PERFORATION AND ABSCESS

What Are the Surgical Options for Management of Perforated Diverticulitis?

Acute diverticulitis may be complicated by free perforation or abscess (Hinchey 3&4). Contamination of the peritoneal cavity with pus or feces presents acutely with classic signs of generalized peritonitis including fever, leukocytosis, and diffuse abdominal tenderness. Treatment includes IV fluid resuscitation, broad spectrum antibiotics, and urgent laparotomy. Classically, the involved segment of sigmoid colon is resected. Proximally, resection should encompass all acutely inflamed colon, leaving margins of compliant bowel. Resection of areas of colon with diverticulosis but without active inflammation is not indicated. The distal extent of resection should ultimately be the intraperitoneal rectum, defined at the convergence of the tinea coli. However, if a colostomy is to be performed, leaving unaffected distal sigmoid as part of the distal pouch is acceptable at the initial operation, with resection to the proximal rectum being performed at the time of colostomy closure. If the entire sigmoid colon is not excised distally, recurrence rates of 12% can be expected.(57)

Controversy exists in whether a one- or two-stage procedure is preferable in the setting of perforated disease. A three stage procedure—first creating a loop transverse colostomy, then sigmoid resection and colorectal anastomosis, followed by colostomy closure—is mentioned for historical interest only. This approach was ultimately shown in randomized trials to lead to higher morbidity and mortality than alternatives.(58, 59) The contemporary gold standard has been a two-stage procedure involving sigmoid colectomy with end colostomy and closure of the rectosigmoid stump, a variation of the procedure initially described by Hartmann for treatment of rectal cancer. After full recovery, intestinal continuity is restored. However, reversal of end stomas have been shown to carry significant morbidity with major complication rates ranging 5–25% (60–63), and 20–50% of end stomas are never reversed.(64–66) Consequently,

the safety and efficacy of resection and primary anastomosis has been evaluated. A comprehensive review of 98 studies by Salem and Flum in 2004 concluded that morbidity and mortality were equivalent in patients undergoing primary resection and anastomosis compared to those undergoing Hartmann's procedure. (66) Similarly, a decision analysis performed by Constantinides et al. in 2007 found primary anastomosis with diverting proximal loop ostomy to be the procedure of choice when comparing morbidity, mortality, and quality of life years.(67) It is important to note that these studies should be interpreted in the context of the inherent biases and limitations of primarily retrospective reviews. Currently, primary resection and anastomosis remains a viable option in selected cases of perforated diverticulitis.

What Are the Options for Management of Diverticulitis with Abscess?

Diverticulitis may also be complicated by abscess formation (Hinchey 2a & 2b). Small, contained abscesses (generally ≤ 4 cm) (68, 69) may be treated with IV antibiotics alone and a treatment protocol similar to that for acute uncomplicated disease. Larger abscesses require drainage. Percutaneous interventional techniques have altered the management of this group of patients. Hemodynamically stable patients without diffuse peritonitis and with percutaneously accessible abscesses may be treated by a combination of percutaneous drain placement and broad-spectrum antibiotics. Resection may then be delayed until inflammation has resolved, potentially allowing for an elective operation performed in a single stage.(70) Abscesses that are not accessible percutaneously should be treated with open surgical drainage and sigmoid colectomy. In selected cases of well-contained abscess without gross peritoneal contamination or surrounding inflammation, performing a single-stage procedure with immediate creation of a colorectal anastomosis is acceptable.

A single episode of diverticulitis complicated by abscess warrants elective sigmoid colectomy following resolution of the acute disease. A complete colonoscopy should be performed prior to resection. As opposed to uncomplicated disease, the risk of developing severe recurrent sepsis in this group is 41%.(71)

CHRONIC COMPLICATED DIVERTICULITIS: STRICTURE AND FISTULA

Diverticular stricture is a relatively rare complication that results from chronic inflammation of the intestinal lumen. Strictures are most often seen in elderly patients. Those who become symptomatic present with signs and symptoms of large bowel obstruction. Most strictures are short segments, and may be amenable to dilation. Placement of expandable metal stents is somewhat controversial, but may have utility in selected patients.(72) Twenty-eight percent of strictures will require surgical intervention.(73) If possible, endoscopic evaluation to rule out a neoplasm should be performed prior to undertaking resection. If this is not possible, however, cancer should be assumed and an oncologic resection should be performed. The patient should have full colonoscopy after recovery.

Fistulae form in the setting of diverticulitis when an abscess or phlegmon erodes into an adjacent structure. The most common type seen in diverticulitis is colovesical fistula. Ninety percent of patients

with colovesical fistula will develop pneumaturia or fecaluria, although recurrent urinary tract infections may be the only clinical sign. Colovesical fistulae may be difficult to demonstrate by diagnostic testing. Cystoscopy is the most accurate study to detect a fistula (46%) followed by barium enema (20%).(74) Cystography and methylene blue instillation may also be useful adjuncts. Treatment of this complication includes division of the fistula, colon resection, and bladder decompression with a urethral catheter for 7–14 days. Controvery exists over the management of the bladder defect; often, it is a pinpoint defect which can be left alone to close over the ensuing days with bladder decompression. Other common types of fistulae include colovaginal (occurring most often in the post-hysterectomy setting), coloenteric, and colocutaneous fistulae.

EMERGING TECHNIQUES

When Is It Appropriate to Use Laparoscopy to Treat Diverticular Disease?

Laparoscopy has been reported for use in diverticulitis with both acute and chronic presentations. It appears to be safe and effective in selected patients.(75, 76) A laparoscopic approach may have less pain and shorter recovery without an increase in early or late complications (77), however, to date no randomized trials have been performed. Currently, the Sigma trial, a prospective, double-blind, multicenter, comparative trial, is underway, evaluating laparoscopic versus open sigmoid resection for elective indications of diverticulitis. However, previous data indicates that the rate of conversion to an open procedure is related to the operating surgeon's experience with laparoscopy and the stage of disease, with higher conversion rates in cases of complicated diverticulitis.(78)

DIVERTICULAR HEMORRHAGE

Hemorrhage, while not associated with diverticulitis, may occur in association with diverticulosis. The mechanism for developing bleeding is poorly understood, however, rupture of a diverticulum into the vasa recta is believed to be responsible. While a fairly rare complication of diverticulosis, diverticular hemorrhage, is the most common cause of lower gastrointestinal bleeding, accounting for up to 40% of all cases.(79, 80)

SUMMARY

Diverticulitis is an increasingly common disease. With the advent of improved imaging techniques and broad-spectrum antibiotics, outcomes of both complicated and uncomplicated disease have improved. Often, the need for a stoma or a multiple-staged procedure may be obviated. While young patients may not necessarily follow a more virulent course, the overall morbidity associated with an increased number of life years exposed to the disease may warrant elective colectomy after two or more episodes of uncomplicated disease. In the remainder of patients, the number of episodes of uncomplicated diverticulitis is a poor predictor of the development of complicated disease, and the decision for elective sigmoid resection should be made on a case-by-case basis. Immunocompromised patients are the exception to this rule. While several recommendations exist for the evaluation and management of diverticulitis, a paucity of Level I evidence exists to clearly guide treatment.

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49 Perforated peptic ulcers
Meredith S Tinti and Stanley Z Trooskin

A 45-year-old woman with a past medical history significant for nonsteroidal anti-inflammatory drug (NSAID)-dependent rheumatoid arthritis, presents to the emergency department complaining of severe abdominal pain. She reports acute onset of mid-epigastric pain 8 h prior to presentation. Her vital signs are significant for mild tachycardia, and pertinent findings on physical examination include severe abdominal distention, diffuse abdominal tenderness, and diffuse peritoneal signs. An upright abdominal radiograph reveals "free air". The patient receives intravenous (IV) fluid resuscitation, IV antibiotics, and a proton pump inhibitor (PPI) and is then taken to the operating room. A perforated prepyloric gastric ulcer is found along with moderate peritonitis. A Graham Patch is performed.

WHAT IS THE EPIDEMIOLOGY OF PEPTIC ULCER DISEASE?

The incidence and prevalence of peptic ulcer disease (PUD) has severely decreased over the last four decades but still represents a significant health problem. Approximately 500,000 people are diagnosed with PUD each year in the United States.(1) Although the recent advances in pharmacologic therapy (antisecretory agents and Helicobacter pylori treatment regimens) and endoscopic techniques have not eliminated the disease process, they have changed the natural history of PUD. Outpatient symptomatology has been successfully treated and therefore there has been a dramatic decline, by approximately 85% over the last three decades, in the need for elective operative therapy for intractable PUD.(2–4) These treatments have not changed the complication rate of PUD (2–10%) (4) and thus the number of emergency surgeries performed for bleeding, perforation, and obstruction has remained the same.(5) This is potentially explained by the increase in both NSAID users and elderly patients seen during the same time period.(6) The United States has seen a decreased perforation rate in men and an increased perforation rate in women over the last three decades. This too, can be correlated to changes in NSAID use and tobacco smoking patterns.(7)

Complications occur in all types of gastrointestinal (GI) ulcers but are much more common in duodenal ulcers. Hemorrhage occurs in 20–30% of peptic ulcers, gastric outlet obstruction in 5%, and perforation in 2–10%.(8) This perforation rate is equivalent to 11 operations per every 100,000 people.(9) Perforated gastric ulcers have a much higher mortality rate than perforated duodenal ulcers and this reportedly ranges 10–40%.(5)

Gastric ulcers account for approximately 5% of all PUD but require operation much more frequently than duondenal ulcers. (10) Ninety-five percent of gastric ulcers are benign. Ulcers in the fundus are rare but are almost always malignant.(11) Giant gastric ulcers, those greater than 2 cm in diameter, which were previously thought to be malignant, are benign 90% of the time. (8) Duodenal ulcers are almost always benign.

WHAT IS THE PATHOPHYSIOLOGY OF PEPTIC ULCER DISEASE? HAS IT CHANGED?

Peptic ulcers occur when there is an alteration in the balance between acid production and mucosal protective mechanisms. There are two major etiologies of this imbalance: H. pylori infection and NSAID use. H. pylori infection is present in 75% of gastric ulcers and greater than 90% of duodenal ulcers, (8) although only 15–20% of people colonized with H. pylori will develop PUD in their lifetime.(8)

Several recent meta-analyses done by Huang et al. (12) and Kurata and Nagawa (13) demonstrated that there is a definite synergism between H. pylori infection and NSAID use and between H. pylori and cigarette smoking in the formation of complicated PUD.(5) More than half of patients with complications of PUD report recent use of NSAIDs (4).

Although the old theory of "too much acid" causing PUD can be explained by H. pylori and NSAIDs in almost all of the cases, there are some cases of PUD in which another explanation is needed. In approximately 33% of patients with duodenal ulcers, the basal acid output (BAO) and the maximum acid output (MAO) are increased. A BAO greater than 15 mEq/h puts one at greatest risk. The increased BAO is frequently observed in patients with increased parietal cell mass (increase acid production to any stimulus) and in patients with accelerated gastric emptying (increased acid load in the first portion of the duodenum). These same levels of BAO and MAO are seen in Type II (gastric and duodenal) and Type III (prepyloric) gastric ulcers, but not in Type I (lesser curvature at the incisura), Type IV (juxtaesophageal), and Type V (anywhere secondary to medication) ulcers.(2)

QUICK REVIEW OF GASTRIC ACID SECRETION AND DUODENAL PROTECTIVE MECHANISMS

Acid secretion is controlled by several types of specialized cells. G cells in the gastric antrum release gastrin. Gastrin activates enterochromaffin cells in the body of the stomach and these secrete histamine. Histamine, in turn, stimulates parietal cells to secrete acid. Gastrin also directly promotes the growth of parietal cells and enterochromaffin cells.(12) Antral D cells secrete somatostatin which inhibits gastrin production.

The epithelial cells of the stomach and duodenum secrete mucus in response to an acid load and to cholinergic stimulation. This mucus helps form a gel layer that is impermeable to acid and pepsin. Other gastric and duodenal cells secrete bicarbonate to aid in buffering acid near the mucosal cells. Prostaglandin E increases the production of both bicarbonate and the gel layer.(11) When acid does penetrate the protective layers and enters the epithelial cells, ion pumps in the basolateral cell membranes are activated to remove excess hydrogen ions and restore intracellular pH.

WHAT IS THE ROLE OF HELICOBACTER PYLORI INFECTION IN PEPTIC ULCER DISEASE?

Unlike other bacteria, H. pylori is able to survive in the acidic environment of the stomach because of its urease enzyme which converts urea into ammonia and bicarbonate and creates a buffered environment for its own survival. The bacteria lives in the mucus layer above the epithelium and causes PUD by altering acid secretion and by inducing gastroduodenal mucosal damage.

The bacteria causes an inflammatory response which results in cytokine stimulation of G cells and parietal cells and inhibits the production of somatostatin. The hypergastrinemia has two major effects. It causes an acid hypersecretion that overwhelms the duodenal protective mechanisms and it leads to parietal cell hyperplasia/metaplasia in the duodenum. The metaplasia creates a mucus layer in the duodenum that allows H. pylori to colonize the area and reduces duodenal bicarbonate secretion.(5, 7, 9, 15) This infection, just like any other infection, stimulates an inflammatory response with host cells that further damages the mucosa. H. pylori secretes toxins that act locally on the epithelium and it produces proteases that degrade the mucus layer.(5, 14)

WHAT ROLE DO NSAIDS PLAY IN THE DEVELOPMENT OF PEPTIC ULCER DISEASE?

The chronic use of NSAIDs significantly increases the risk of complications of PUD and is the most common cause of PUD in patients who do not have H. pylori. Age over 60 years, prior GI complication, high NSAID dose, and concurrent steroid and/or anticoagulant use, greatly increase the risk of ulcer complications. (16, 17) The cyclooxygenase-1B inhibitor (COXIB) drugs have a slightly lower risk of upper GI complications than the traditional NSAIDs but only at lower doses, (16, 18) and the cyclooxygenase-2 inhibitor (COX2) drugs have not been found to change the overall outcome of GI complications when compared to traditional NSAIDs.(19)

NSAIDs have a local topical effect on gastric mucosa which cause submucosal erosions. They also inhibit the formation of prostaglandins and thus inhibit their mucosal protective effects such as the production of bicarbonate and the increase in mucosal blood flow.(1)

All of these effects are intensified with the coexistence of an H. pylori infection.

ARE THERE OTHER CAUSES OF PEPTIC ULCER DISEASE?

Other causes of PUD, although less common, include Crohn's disease, Zollinger–Ellison Syndrome (ZES), hyperparathyroidism, systemic mastocytosis, steroid use, cigarette smoking, and cocaine use.

Zolllinger–Ellison Syndrome

ZES, or gastrinoma, is caused by a tumor of the pancreatic islet cells that produce gastrin. These tumors can arise sporadically from mutations in oncogenes such as Her-2/Neu or as part of the Multiple Endocrine Neoplasia Type 1 (MEN 1) syndrome. These are responsible for 0.1–1.0% of duodenal ulcers. ZES frequently causes ulcerations in atypical locations such as the distal duodenum or jejunum. Fifty percent of ZES ulcers are solitary and 50% are considered malignant (as they have lymph node and/or hepatic involvement).(20, 21)

Cigarette Smoking

Smoking increases the gastric acid secretion and duodenogastric reflux. It inhibits prostaglandin production and decreases pancreaticoduodenal bicarbonate secretion.(5)

Cocaine Use

Recent literature (22) has identified crack cocaine with juxtapyloric peptic ulcers that have an increased propensity to perforate. The etiology has not yet been elucidated but many speculate that these ulcers are secondary to a local ischemia from the drug-induced vasoconstriction rather than from an acid imbalance.

HOW DO PATIENTS WITH PEPTIC ULCER DISEASE AND PERFORATED PEPTIC ULCER PRESENT?

The typical symptoms of noncomplicated PUD include episodic burning pain in the epigastrium that occurs on an empty stomach and is relieved by food intake, antacids, or antisecretory agents. A small proportion of patients will have vomiting, heartburn, or intolerance to fatty foods. Patients with duodenal ulcers will be more likely to have pain relieved by food intake than patients with gastric ulcers. Weight loss secondary to fear of food intake is more common with gastric ulceration than with duodenal ulceration. In female pregnant patients, nocturnal vomiting during the third trimester can be seen.(1) Those patients with ZES are more likely to present with diarrhea as part of their symptomatology. (20) Physical examination in noncomplicated PUD is unreliable.

Patients with perforated PUD usually present with an acute onset of abdominal pain. Often, they can tell you the exact time of the perforation. The pain starts in the epigastrium but by the time of presentation in the emergency department, it is generalized and associated with diffuse peritonitis. Elderly patients may not manifest these symptoms and may instead present with nonspecific complaints such as confusion, restlessness, falls and abdominal distention.(1)

At the time of presentation with a perforated ulcer, it is important to ascertain whether the patient has a history consistent with chronic PUD, either by prior treatment, current medications or pre-existing symptoms of noncomplicated disease.

HOW DO WE DIAGNOSE PERFORATED PEPTIC ULCER DISEASE?

The differential diagnosis of perforated PUD is made by history and physical examination (as discussed in section "How do patients with peptic ulcer disease and perforated peptic ulcers?"). Upright chest radiographs are commonly used as an adjunct in the diagnostic process. Upright films will show pneumoperitoneum ("free air") in 80–90% of the cases.(5) If pneumoperitoneum is identified on plain radiographs, there is no need for further studies.

Ultrasound is less sensitive for detecting free air but could be used to identify other indirect findings of perforation such as

free fluid and decreased peristalsis when the diagnosis remains in question. Computerized tomography (CT) scans are more sensitive for detecting pneumoperitoneum than the other modalities but should ideally be performed at least 6 h following the onset of symptoms.(23) Some authors suggest the use of oral contrast medium with CT scanning to identify the site of perforation and the presence of ongoing leakage.(24)

ONCE WE HAVE A DIAGNOSIS OF PEPTIC ULCER DISEASE, HOW DO WE TEST FOR H. PYLORI INFECTION?

Every patient diagnosed with PUD should be screened for H. pylori infection. There are a variety of tests that can be used to make the diagnosis. The positive predictive value of each of the tests is quite high, but the negative predictive value is very low. Therefore, patients can be reliably treated based on a positive screening test but clinical evaluation is needed before deciding not to treat a patient with a negative test result. All patients with complicated PUD should be treated for H. pylori infection.

The gold standard test is the histologic examination of a mucosal biopsy using special stains. Thus, all gastric ulcers should be biopsied at the time of operation or endoscopy. Other tests for H. pylori infection include a serologic test, a urea breath test, a rapid urease test, and a fecal antigen test. The serologic test is noninvasive and has a sensitivity > 80% and a specificity of 90%. It is not reliable if the patient has already received antibiotic therapy for H. pylori and it cannot be used to confirm disease eradication because the serum will remain positive for an indeterminate length of time. The urea breath test is a newer modality and involves the ingestion of radio-labeled urea with subsequent analysis of expired air. This test has a high sensitivity and specificity but is used mostly to confirm cure following treatment rather than to make the primary diagnosis. The rapid urease test requires a biopsy specimen and is a simple laboratory test but has a high false-negative rate (especially after PPIs or antibiotics have been given). The fecal antigen test that detects active infection is a very simple test and can be used for diagnosis or confirmation of cure.(5, 25)

WHAT ARE THE INDICATIONS FOR SURGERY IN PATIENTS WITH PEPTIC ULCER DISEASE?

The indications for surgery for PUD have recently been limited to the treatment of complicated PUD. However, because of the high mortality rate following emergency surgery for perforated PUD, many are suggesting nonoperative management rather than surgical management in high-risk patients. High risk is defined as the presence of severe comorbidities, perforation greater than 24 h, and hypotension on presentation.(26) Crofts et al. (27) determined that nonoperative management with nasogastric suction, fluid resuscitation, and antibiotics can be effective in the treatment of perforated PUD if the site of perforation has sealed.(28) Failure to improve within 24 h should then prompt an operation. Each case must be individualized, and nonoperative management should not be undertaken if a contrast study of the upper gastrointenstinal tract shows continuing free perforation.

WHAT ARE THE TREATMENT OPTIONS FOR PERFORATED PEPTIC ULCER DISEASE?

Does Nonoperative Management Have a Role?

As discussed in the previous section on the indications for operation in the perforated PUD, conservative, nonoperative management can be employed for certain populations with a high mortality risk and no ongoing perforation.

What Are the Surgical Options? When Do We Use Them?

Surgery for PUD has a long history with many surgical options. Many procedures have gone out of favor due to complications, side effects, and inadequacy, leaving highly selective vagotomy (HSV) or truncal vagotomy with pylorplasty or gastrojejunosotomy, vagotomy with antrectomy, and omental patch closure as the current options.

Highly selective vagotomy
HSV is a tedious but safe operation , that can be performed laparoscopically, with minimal side effects. It has a higher recurrent ulcer rate than the other procedures (10–20%). It is not useful for Type II or Type III gastric ulcers or for complicated PUD.(5, 9, 29)

Truncal vagotomy
Truncal vagotomy with drainage procedure can be performed safely and quickly by experienced surgeons (but perhaps not as readily by the latest generation of surgeons who are trained in the current era of medical management of PUD). Truncal vagotomy is very useful in complicated ulcer disease. It reduces peak acid secretion by 50%.(7) It requires frozen section confirmation of vagal trunks, has a significant side effect profile and has a recurrent ulcer rate of 10%.(5, 7)

Vagotomy with antrectomy
Vagotomy with antrectomy is most effective at reducing acid secretion and has a recurrence rate of 0–2%. But, this operation has a 20% rate of post-gastrectomy and post-vagotomy syndromes and has a significant associated mortality. The mortality risk increases with patient comorbidities and with emergency surgery for complicated PUD. It should be avoided in hemodynamically unstable paitents and those with extensive inflammation since the anastamosis may be compromised.(5, 7, 30)

Omental patch closure
Omental patch closure is a quick and simple procedure that is very useful in perforated PUD. It has long been the recommended treatment in patients with multiple comorbidities, those that are hemodynamically unstable and those with exudative peritonitis. It is not useful in Type IV gastric ulcers and may not be the optimal treatment in a stable patient with a perforated Type I gastric ulcer.(7) The traditional teaching has been that patch closure should not be used for chronic ulcer perforations in stable patients due to a high ulcer recurrence rate (25%). However, the determination of acute ulceration versus chronic ulceration may be very difficult to make at the time of surgery and current successes with medical therapy have nearly eliminated this concern.

Numerous authors in recent years have prospectively investigated peptic ulcer recurrence rates after simple patch closure and H. pylori eradication and have reported high success rates. In a landmark paper, Ng et al. (31) reported a 1-year ulcer recurrence of 4.8% following H. pylori treatment and surgical intervention, with > 75% of the procedures being simple patch closure. Bose et al. (32) reported a significantly decreased recurrence rate with H. pylori eradication. Rodriguez-Sanjuan and colleagues (33) had similar results but had even lower recurrence rates (0–2.6%) for nongastric ulcers (duodenal, prepyloric, and pyloric). They also found that although their gastric ulcer recurrence rate was low (4.3%), the gastric recurrences frequently presented as reperforation.

IS THERE A ROLE FOR LAPAROSCOPIC SURGERY IN THE TREATMENT OF PEPTIC ULCER DISEASE? WHAT ABOUT FOR PERFORATED PEPTIC ULCER DISEASE?

Laparoscopic surgery has recently gained popularity in the treatment of both elective and emergency surgery for PUD. There are a limited number of studies addressing these issues but there are some data to suggest that simple suture of ulcerations, omental patch closure, and vagotomy can all be performed laparoscopically.(34, 35) Lau's meta-analysis (36) reports that laparoscopic repair of perforated PUD is safe and does confer some short-term benefits but has a higher reoperation rate than the traditional open operations.

WHAT ARE THE KEYPOINTS TO REMEMBER IN MANAGING PATIENTS WITH PERFORATED PEPTIC ULCER DISEASE?

1. Biopsy of all perforated gastric ulcers is required.
2. No single approach is ideal for all patients. Surgeons must be prepared to individualize all treatment plans.

IS THERE A SIGNIFICANT POSTOPERATIVE MORBIDITY AND MORTALITY ASSOCIATED WITH REPAIR OF A PERFORATED PEPTIC ULCER DISEASE?

Despite current advances in medical and surgical therapy, the morbidity and mortality associated with perforated PUD remains very high and this area has remained a topic of current research efforts. Comorbidities and preoperative shock are well-established independent risk factors for a poor outcome following emergency surgery.(5, 28, 37) Kocer et al. (38) added age, ASA score, time before surgery, and performance of a definitive operation to the list of significant risk factors. Egberts and colleagues (39) used the *Physiologic* and Operative Severity *Score* for the enUmeration of Mortality (POSSUM) score to confirm the previous findings.

ONCE THE OPERATION FOR PERFORATED PEPTIC ULCER DISEASE IS COMPLETE, ARE THERE ADJUNCTIVE MEDICAL TREATMENTS THAT SHOULD BE USED?

Proton Pump Inhibitors
Patients with perforated PUD who do not undergo an acid-reducing operation should be placed on acid suppression therapy for life. Eighty to ninety percent of peptic ulcers will heal with the chronic use of antacid medications.(40) Antacids are as effective as H2 blockers but are associated with more side effects and require more frequent administration. Several randomized control trials have demonstrated that ulcer healing occurs faster and in a higher percentage when PPIs are used in place of H2 blockers.(41) PPIs must be taken on a regular basis (not as needed) and should be administered before the first meal of the day.

Discontinuation of Nonsteroidal Anti-inflammatory Drugs
Cessation of all NSAIDs (and any other offending agents) is highly recommended in all patients with complicated PUD. This recommendation includes the discontinuation of cardio-protective doses of aspirin therapy. There are, however, certain patient populations that require chronic anti-inflammatory medications (i.e., rheumatoid arthritis, transplant patients). In these patients, the traditional NSAIDs can be substituted with the more specific but potentially cardiotoxic COX2 inhibitors and supplemented with cytoprotective agents.

Medications for Mucosal Cytoprotection
Rostom et al. performed a meta-analysis of randomized control trials and concluded that misoprostol, PPIs, and double-dose H2 blockers are equally effective in preventing PUD from NSAID use. They also showed that sulcralfate is not effective.(42) Although the theory of enhancing the weakened mucosal barrier seems worthwhile, there has been no added benefit identified in patients with complicated PUD.

Misoprostol is a prostaglandin E2 analog that decreases mucosal injury but that has severe GI side effects secondary to its potent stimulation of smooth muscle. This has severely limited its clinical use.

Treatment of Helicobacter pylori and verification of eradication
Treatment of H. pylori with a 2-week course of either a triple regimen or quadruple drug regimen results in 90–98% eradication rate.(43) Because the recurrence rate of ulceration without complete eradication is high, 38–70% versus 5% with eradication (4, 32), endoscopic reexamination to confirm cure is necessary. Triple therapy for H. pylori eradication includes a PPI and two antibiotics, commonly metronidazole and tetracycline or amoxicillin and clarithromycin. Quadruple therapy adds bismuth to one of the triple drug regimens and is used in areas where there is high metronidazole resistance or triple therapy treatment failures.(44)

After completion of drug therapy, at least 1 month's time should pass before testing for cure is attempted. Testing for cure can be accomplished by any of the methods for H. pylori detection that were discussed in the diagnosis section but repeat endoscopy is most accurate. According to Ng et al. endoscopy performed at 8 weeks following treatment showed a ulcer cure rate > 80% in both the H. pylori treatment group and the PPI alone group. But, at 1 year following treatment, the ulcer recurrence rate was 4.8% in the H. pylori group versus 38.1% in the PPI alone group.(29)

Table 49.1 Evidence-Based Recommendations for the Treatment of *H. Pylori*.

Stop NSAID use (due to synergistic ulcerogenic effects) (5, 45)	1B
Initial drug therapy	1A
Triple therapy for 10–14 days (5, 44, 46–49)	1B
H2 blocker plus two antibiotics	
PPI, amoxicillin and clarithromycin	
PPI, amoxicillin and metronidazole	
PPI, metronidazole and clarithromycin	
(for penicillin allergic)	
Quadruple therapy for 10–14 days	1B
H2 blocker, bismuth, metronidazole, tetracycline (44, 49, 50)	
Two-Part therapy	2C
PPI and amoxicillin for 5 days then PPI, clarithromycin and tinidazole for 5 days (44)	
Quadruple therapy with PPI for 7 days (51, 52)	2B
Quadruple therapy with PPI for 1 day (53)	2B
Retreatment after failure (14 days)	
Quadruple therapy (5, 32, 49)	1A
PPI, bismuth, metronidazole, tetracycline	
Triple therapy with levofloxacin (44, 54)	1B
PPI, amoxicillin, levofloxacin	
Rescue therapy after multiple failures (14 days)	
Rifabutin-based therapy (55, 56)	1B
PPI, amoxicillin, rifabutin	
Furazolidone-based therapy (44, 55, 57)	(not available in the United States)
Vaccination (5, 45)	2C
Confirmation of cure in complicated PUD (5, 25, 44)	
Stool antigen test	1C
Urea breath test	1C
Endoscopic biopsy if being done for other reason	1C
Serology	(not recommended)
Surgical treatment (5, 32, 58)	
Antrectomy	2A

If eradication has not been achieved at the time of retesting, a second course of therapy should be initiated. Quadruple drug therapy should be used at this time regardless of which regimen was used during the initial treatment phase.(5, 33)

As for the future, research on an H. pylori vaccine continues. (45) See Table 49.1.

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50 Acute mesenteric ischemia
Daniel T Dempsey

Case 1: You are asked to see a 59-year-old woman in the medical intensive care unit (ICU). The stat consult says "rule out ischemic bowel". The patient is an insulin-dependent diabetic admitted to the ICU three days ago with congestive heart failure and anemia. She was awakened at 3 a.m. with severe generalized abdominal pain. At 5 a.m. she passed a loose, brown, heme-positive stool. You see her at 7 a.m. She is pale and obviously uncomfortable. The pain is now "a 10 out of 10", and she is requesting "another shot of morphine". Physical exam reveals a pulse of 120/min (irregularly irregular), respiration rate of 20/min, and blood pressure (BP) of 110/70. There is a scar from a left carotid endarterectomy and a median sternotomy (CABG x 3 done 4 years ago). There is moderate *jugular venous distension* (JVD) and bibasilar crackles in the lung fields. The abdomen is mildly tender to deep palpation in all four quadrants without peritoneal signs and without palpable masses. Bowel sounds are present and unremarkable. There is a faint epigastric bruit. Femoral pulses are normal bilaterally. Oxygen saturation on 4 L/min. nasal O_2 is 95%. Urine output is 20 cc/h for the past 3 h. *Electrocardiogram (*ECG) shows atrial fibrillation and no acute changes. An upright portable chest X-ray shows cardiomegaly and mild pulmonary edema. There is no subdiaphragmatic pneumoperitoneum. Laboratory studies from 5 a.m. show a hematocrit of 27 percent and white blood cell (WBC) of 18,000/ml. Creatinine is 1.8. Liver function tests are normal; platelet count, prothrombin time (PT), international normalized ratio (INR), partial thromboplastin time (PTT) are normal. Anticoagulants have been held for the past 3 days because of the anemia. The patient is to have an upper endoscopy at 11 a.m.

WHAT IS THE PATHOPHYSIOLOGY OF ACUTE MESENTERIC ISCHEMIA? (TABLE 50.1)

Acute mesenteric ischemia may be defined as a sudden decrease in blood flow to a level below that required to meet the metabolic demands of the abdominal viscera supplied by the celiac, superior mesenteric, and/or inferior mesenteric arteries. Most commonly the small and/or large bowel are effected.(1–4)

The causes of clinically significant acute mesenteric ischemia are arterial embolus (50%), arterial thrombosis (20%), low flow state (20%), mesenteric venous thrombosis (5%), and other (5%). Included in the other category would be situations such as sigmoid ischemia due to inferior mesenteric artery occlusion as a result of abdominal aortic replacement (see Case 2); or gastrointestinal (GI) ischemia secondary to visceral vessel occlusion as a result of aortic dissection. The overall mortality rate of acute

Table 50.1 Risk Factors for Acute Mesenteric Ischemia.

Cardiac arrhythmia
Acute myocardial infarction
Ventricular aneurysm
Cardiomyopathy
Cardiac pacemaker
Cardiac defibrillator device
Endocarditis
Atrial septal defect (paradoxical embolism)
History of heart valve replacement
History of previous embolic event
Known hypercoaguability
Recent warfarin or heparin treatment
Clinical evidence of atherosclerosis
Recent history of cardiac or aortic catheterization
Low cardiac output
Current or recent vasopressor therapy
Recent ergotamine or cocaine exposure
Known or suspected aortic dissection
Aortic coarctation
History of vasculitis or Buerger's Disease

mesenteric ischemia is about 50% and has not improved much in the past three decades, although admittedly the patients presenting today with this problem may be sicker and more complex than in the past.(5, 6)

Major mesenteric emboli usually involve the superior mesenteric artery (SMA) distribution perhaps because of a more favorable angle with the aorta than the celiac or IMA. The site of origin of the embolus is frequently the heart, and multiple previous (or future) episodes of embolization are not uncommon. Cardiac conditions associated with thromboembolic phenomena include arrhythmia (particularly atrial fibrillation), acute myocardial infarction (AMI), ventricular aneurysm, and valvular disease.(7) Most often mesenteric embolism from a cardiac source occurs spontaneously but it may occur after catheter-based cardiac treatment or after cardiac surgery. An aortic source is the second most common site of origin for SMA emboli. Usually these are spontaneous events, but occasionally they are seen following instrumentation of the aorta and presumed dislodgement of atheromatous material, for example, following left heart cardiac catheterization or coronary angiography, carotid stenting, or thoracic stent grafting. The typical SMA embolus lodges at the major branch point just distal to the middle colic artery, preserving the blood supply to the transverse colon and very proximal jejunum. Unless flow is restored promptly, bowel necrosis occurs from the proximal jejunum to the ascending colon,

and the only hope for survival is massive bowel resection and long-term total parenteral nutrition (TPN) and/or small bowel transplantation. The different patterns of intestinal ischemia with embolism are myriad, and depend on both the size and number of emboli at the initial event. Persistent vasospasm can significantly compromise the reestablishment of mesenteric blood flow even after the embolic material has been removed or lysed. If flow is restored to severely ischemic but still viable bowel, there may be a significant ischemia/reperfusion injury. Rarely, the washout of potassium and acid from the underperfused mesenteric bed can result in cardiac arrest. More commonly, a systemic inflammatory response ensues with multiple organ dysfunction and not infrequently death.

Acute mesenteric ischemia from **thrombosis** usually occurs in the setting of chronic intestinal ischemia and diffuse atherosclerosis.(8–10) Because the latter is typically a slowly progressive disease, there is time for a compensatory increase in collateral flow in the setting of compromised inflow in any of the three major vessels supplying the gut (celiac, SMA, IMA). By the time the patient presents with the classic symptoms of chronic mesenteric ischemia (postprandial "intestinal angina," sitophobia, weight loss), evaluation usually shows severe inflow compromise at two of the three arterial trunks, along with significant collateral flow.(11, 12) An acute thrombosis of one of the major arterial trunks, usually the SMA, can precipitate acute intestinal ischemia. This thrombus usually involves the origin of the SMA (unlike the embolus discussed earlier), and the thrombosis may occlude (or propagate past) the origin of the pancreaticoduodenal (PD) arcade and/or the middle colic artery. This can result in necrosis of the entire midgut from the ligament of Treitz to the mid-transverse colon. However the distribution of the ischemia may vary based on the status of the celiac and inferior mesenteric artery (IMA), and the status of the collateral connections with the SMA PD arcade and middle colic, respectively). Vasospasm is a common complicating factor. An uncommon cause of acute intestinal ischemia is inadvertent surgical interruption of important mesenteric collaterals. For example, if a patient with a severely stenotic SMA has a pancreaticoduodenectomy (Whipple operation), parts of the small bowel may become ischemic because they are now deprived of collateral flow from the celiac via the PD arcade. A similar situation could occur after formal left hemicolectomy which interrupts the collateral flow to the SMA from the IMA via the middle colic and associated arcades.

Low flow, as a cause of acute mesenteric ischemia (**nonocclusive mesenteric ischemia** [NOMI]), is usually seen in patients with low cardiac output or profound hypovolemia.(13, 14) Not uncommonly it presents in patients in cardiogenic shock, or in those on vasopressors. Hemodialysis treatment is another well-recognized setting for acute mesenteric ischemia from low flow. As cardiac output falls there is a proportional redistribution of blood flow away from the abdominal viscera, mediated in part by mesenteric vasoconstriction, a process exacerbated by the administration of vasopressors. When cardiac output is restored to physiologically appropriate levels, mesenteric vascular spasm may cause mesenteric ischemia to persist. The distribution of severe bowel ischemia and/or necrosis is typically patchy and it

Table 50.2 Risk Factors for Mesenteric Venous Thrombosis (ref 10).

Malignancy
Oral contraceptives
Pancreatitis
Splenectomy
Hypercoagulable states
Thrombocytosis
Polycythemia vera
Paroxsysmal nocturnal hemoglobinuria
Factor V Leiden
Protein C or S deficiency
Cirrhosis/portal hypertension
Intraabdominal inflammation/infection
Abdominal operation

may be diffuse, occasionally involving areas supplied by all three major vessels (celiac, SMA, and IMA).

Mesenteric venous thrombosis may lead to arterial hypoperfusion and full thickness bowel ischemia and necrosis.(15, 16) Mesenteric venous thrombosis that causes clinically significant acute mesenteric ischemia almost always involves the superior mesenteric vein (SMV). In most cases there is an identifiable etiologic factor such as hypercoagulability, intra-abdominal cancer or inflammation, cirrhosis, portal hypertension, or recent operation (e.g., splenectomy, Whipple operation). (Table 50.2). In patients with hypercoagulability, the thrombotic process begins in the small venules at the periphery whereas with intra-abdominal conditions such as pancreatitis or recent operation, the clot begins in the large named veins of the mesenteric circulation. About half of the patients who develop clinically significant mesenteric venous thrombosis have a history of deep venous thrombosis or pulmonary embolism.

The mucosa is the most metabolically active layer of the intestine and not surprisingly the majority of intestinal blood flow goes to the mucosa and submucosa. These layers are thus susceptible to ischemia, and an acute drop in blood flow below that necessary to meet metabolic demands leads to a breakdown (first microscopic then macroscopic) of the mucosal border. Initially the gross changes are patchy and reversible, but eventually irreversible ischemic necrosis ensues. A compromise in the barrier function of the mucosa results in movement of bacterial products into the submucosa where they can enter the lymphatics and venules, giving rise to systemic sepsis. When this process occurs in areas with reversible damage, restoration of blood flow may lead to a large bolus of bacteria, and bacterial products being delivered to the portal and systemic circulation result in septic shock and systemic inflammatory response syndrome. An even more important factor in the development of these two problems which commonly complicate the management of these patients is intestinal **ischemia/reperfusion**. This phenomenon activates neutrophils and upregulates endothelial adhesion molecules that mediate remote organ injury, for example, in lung, kidney, liver, and increases mucosal injury in reperfused bowel.(17–19)

WHAT IS THE DIFFERENTIAL DIAGNOSIS OF ACUTE MESENTERIC ISCHEMIA?

Ischemic bowel should be in the differential diagnosis of most adult patients with acute abdominal pain because it is one of those diagnoses that if not considered early, the patient may be lost. In the alert patient the diagnosis can often be made early if suspected during the initial evaluation of the acute abdomen.(20, 21) In the unconscious or obtunded individual the diagnosis is made later, often as part of a work up for increasing sepsis, ileus, and/or acidosis. In patients with acute mesenteric venous thrombosis, the onset of abdominal pain is more gradual than in those with acute mesenteric arterial insufficiency. When evaluating and treating patients who probably have acute mesenteric ischemia, particularly those who have been symptomatic for a few hours or less, **it is important not to waste time**.(22) Just as the neurologist might say "time is brain" or the cardiologist might say "time is myocardium" when dealing with an evolving acute cerebral or myocardial infarction, respectively, the surgeon and the team caring for a patient with probable acute mesenteric ischemia must view this as an emergency which requires prompt and definitive diagnosis and treatment. This is the only way to limit visceral infarction, reduce ischemia/reperfusion injury, and the attendant systemic inflammatory response, and to ultimately improve the mortality rate for this devastating clinical problem.

> The patient described earlier has a 4-h history of severe generalized abdominal pain and multiple risk factors for bowel ischemia including atrial fibrillation, atherosclerosis, and hypoperfusion. She has intestinal ischemia with impending infarction until proven otherwise, and time is of the essence. Other possible diagnoses include acute pancreatitis, acute diverticulitis, perforated ulcer, and leaking abdominal aortic aneurysm, but these are less likely. Severe abdominal pain out of proportion to physical findings is a recognized hallmark of acute intestinal ischemia.

> Recommendation (Grade 1B): Patients, especially those with risk factors (Table 50.2) who develop acute abdominal pain out of proportion to physical findings should be considered to have acute mesenteric ischemia until proven otherwise.

WHAT IS THE INITIAL TREATMENT OF SUSPECTED MESENTERIC ISCHEMIA?

Fragmentation of care is the enemy of the patient with acute mesenteric ischemia. So is therapeutic nihilism. Most patients with acute mesenteric ischemia can be salvaged, but if the patient is to survive with low morbidity, **coordination of care is essential**. To avoid useless tests and delay, a rational and efficient plan of diagnosis and management specific for the individual patient must be developed early. Early and direct verbal communication between attending physicians involved in, or likely to be involved in, the

care of the patient is the key to the treatment. During the initial evaluation, the surgeon should speak with the attending physician or primary care physician requesting the consultation and familiar with the medical condition of the patient. An operating room should be readied and an anesthesiologist should be called by the surgeon. The radiologist responsible for performing and interpreting imaging studies should be directly notified by the surgeon. A vascular surgeon should be called and apprised of the situation if deemed appropriate, particularly if the initial evaluating surgeon does not have the interest or the expertise to revascularize the bowel if necessary. The patient should not fall victim to local turf issues between general surgery, acute care surgery, vascular surgery, interventional radiology, cardiology, and so on.

> Recommendation (Grade 1C): All patients with suspected acute mesenteric ischemia should be evaluated as soon as possible by a surgeon who should be involved in the formulation of an expeditious multidisciplinary management plan. Time must not be wasted with unnecessary tests and/or lapses in communication.

Should the patient be immediately therapeutically heparinized? Thromboembolism, both macroscopic and microscopic, is an essential part of the pathophysiology of acute mesenteric ischemia. Whether the proximate cause of the ischemic event is a large arterial embolism originating in the left atrium, or SMA thrombosis on a pre-existing critical stenosis, or microthrombosis in arterial beds subjected to low flow, or venous thrombosis; ongoing clotting should be inhibited with immediate and therapeutic anticoagulation. This is probably best accomplished with an intravenous (IV) bolus (e.g., 5,000 units) and continuous infusion (e.g., 1,000 units/h) of unfractionated heparin with the goal of maintaining the PTT at twice normal. Therapeutic low-molecular-weight heparins may be equivalent. Patients with known heparin allergy or heparin-induced thrombocytopenia should be given a heparin substitute. Major operations and catheter-directed treatments can be safely performed in the setting of therapeutic heparinization. The potential benefit of limiting the thromboembolic process outweighs the risk of bleeding in most patients. Anticoagulation should be withheld in patients at risk for intracranial hemorrhage and in those with ongoing or recent life-threatening bleeding (e.g., massive GI bleed, large retroperitoneal hematoma). Finally, patients who are "auto-anticoagulated" (INR> 1.8 from liver dysfunction, or platelet count < 50 K) should probably not be heparinized.

> Recommendation (Grade 1B): Patients with known or suspected acute mesenteric ischemia should be therapeutically heparinized immediately.

Should the patient immediately be given IV antibiotics? Patients with acute mesenteric ischemia are at risk for intestinal perforation and bacterial peritonitis, the severity of which may be mitigated by therapeutic levels of broad-spectrum antibiotics. Furthermore, ischemia-induced translocation of luminal bacterial products may contribute to the septic state which commonly

develops in patients with acute mesenteric ischemia. Finally, until definitive imaging and/or operation it must be remembered that the patient may be suffering from some other malady which will benefit from antibiotics, for example, GI perforation from appendicitis, or diverticulitis, or ulcer.

> Recommendation (Grade 1B): Patients with known or suspected acute mesenteric ischemia should immediately be given broad-spectrum IV antibiotics.

Should a Swan-Ganz (S-G) pulmonary artery (PA) catheter be inserted? Optimization of cardiac output and oxygen delivery to the abdominal viscera is important in the management of acute mesenteric ischemia. The patient described has clinical signs of congestive heart failure and visceral hypoperfusion. If she did not have symptoms of acute mesenteric ischemia, she might benefit from PA catheterization and/or echocardiography. But in the scenario presented this could lead to a harmful delay in diagnosis and treatment of the underlying problem. You don't have time to insert the S-G catheter or wait for the cardiac echo. The patient needs a definitive imaging study now (discussed in the following). Insertion of S-G catheter or central venous pressure (CVP) could delay or interfere with the systemic anticoagulation discussed earlier because some clinicians would not initiate systemic anticoagulation until after the satisfactory placement of a PA or CVP catheter. And many would feel uncomfortable about immediate anticoagulation following a fresh inadvertent puncture of the carotid or subclavian artery. In our patient, a transthoracic or transesophageal echocardiogram can be obtained after definitive treatment for acute mesenteric ischemia is begun. This will help to rule out residual intracardiac clot, septal defects, and pericardial effusion and will evaluate ventricular function.

The patient may benefit from low-dose dopamine both to improve cardiac output and mesenteric blood flow, but this remains debatable. Vasoconstrictors should be avoided, and supplemental oxygen should be continued. Diuresis may be considered for the treatment of ongoing congestive heart failure (CHF), but some studies have shown an increase in contrast-related renal insufficiency with furosemide pretreatment.

> Recommendation (Grade 1C): In patients with known or suspected acute mesenteric ischemia, optimization of hemodynamics should occur concurrently with, and not significantly delay, essential diagnostic work up and treatment. Delay may be particularly harmful in patients who have been symptomatic for less than 6 h.

WHAT DIAGNOSTIC TESTS SHOULD BE OBTAINED IN PATIENTS WITH SUSPECTED ACUTE MESENTERIC ISCHEMIA?

Are there additional blood studies that should be ordered? There are a variety of abnormalities in serum levels that have been described in patients with AMI, but most of these are late findings. These include elevations in lactate, anion gap, amylase, D-dimer, C-reactive protein, creatine phosphokinase (CPK), lactate dehydrogenase (LDH), potassium, and phosphate. An abnormal lab value may be reassuring that the patient probably does indeed have acute mesenteric ischemia, but a normal value is not helpful. Again, work up and treatment should not be delayed, pending the result of any particular blood test. The patient described should have a type and screen sent to the lab.

Is urgent endoscopy useful? Most patients with acute mesenteric ischemia do not benefit, and may be harmed, from urgent endoscopy. Air insufflation and scope torquing may be dangerous, and pathognomonic findings are not expected to be found within easy reach of the scope (stomach, duodenum, left colon). The upper endoscopy scheduled for our patient should be cancelled.

What imaging studies should be performed? This decision must obviously be informed by the timely availability of modern equipment and expertise, and the clinical scenario.(2, 4, 23) In the occasional patient with a very acute presentation, peritoneal signs on exam, and a high clinical likelihood of AMI, it may be acceptable for the surgeon to proceed right to the operating room if he/she is prepared to revascularize the bowel. The patient described earlier does not have peritonitis on clinical exam and there is no clear indication for operation, yet. Usually the benefits of high-quality imaging outweigh the disadvantages, and most surgeons generally prefer to get as much preoperative information as they safely can. It is advisable for the surgeon(s) to discuss the imaging plan with the radiologist(s). The three imaging studies to consider in this patient are biplanar contrast arteriography, multidetector computed tomography scan (MDCT) with IV contrast, and magnetic resonance (MR) angiogram with gadolinium. Duplex ultrasound of the mesenteric vessels is not recommended in patients with suspected AMI. There is a risk of contrast-related renal insufficiency with arteriography and MDCT. *With an elevated creatinine, diabetes, CHF, and probably renal hypoperfusion, our patient is at increased risk for renal failure from IV contrast, and this risk is dose-related. This risk can be minimized by hydration, the avoidance of high osmolar contrast, and the preprocedure administration of oral or IV N-acetylcysteine.(24)*

Biplanar contrast arteriography remains the standard imaging procedure in suspected acute mesenteric ischemia.(2, 25) Well-recognized pathognomonic findings for thromboembolic occlusion, NOMI, and mesenteric venous thrombosis make the likelihood of definitive diagnosis with mesenteric arteriography high. It is also the only imaging modality that allows therapeutic options. If the patient with AMI is found on arteriogram to have thromboembolic arterial occlusion and flow cannot be successfully restored by endovascular techniques or if the patient has clinical peritonitis, then the patient should be taken directly to the operating room for exploratory laparotomy, surgical revascularization, and if necessary, bowel resection. If flow is successfully restored with thrombolysis and/or dilation/stenting, or if the patient has NOMI or mesenteric venous thrombosis, the patient may not require immediate laparotomy unless peritonitis is present on clinical examination; or unless another imaging study (usually MDCT scan) shows a high likelihood of bowel necrosis or perforation. In the patient with peritonitis and probable AMI on MDCT, operation should not be significantly delayed for angiography. Whether the brief delay attendant to readily available angiography and the accompanying dye load are worth it, has not

been tested in a clinical trial. But readily available angiography confirms the diagnosis and allows for local infusion of papaverine postoperatively as well as follow-up imaging of the treated mesenteric vasculature.

The modern MDCT, performed with IV contrast, provides vascular images that rival standard arteriography.(26, 27) MDCT scanning also provides valuable bowel and mesenteric imaging which can help estimate the likelihood of irreversible bowel compromise and thus can help predict the need for subsequent laparotomy. If the equipment is available, the test can be performed and interpreted more quickly than arteriography and it is less invasive. For all these reasons, increasingly this study has been performed even before the surgeon first reaches the bedside of the patient with suspected AMI. If MDCT scan provides a definitive diagnosis, then the appropriate therapeutic plan may be formulated based upon the clinical situation and the local clinical expertise. Unless the diagnosis is mesenteric venous thrombosis, the next step for the patient with AMI will usually be the operating room or the angiography suite. Clearly if both MDCT and arteriography are appropriate for a given patient they should both be performed. Recognizing this, it is important to limit the total IV contrast load, and high osmolar contrast material should not be used. High-quality CT angiography performed with modern MDCT scanning may help focus, and thus help limit, the contrast injections required on subsequent standard arteriography. *For example, if MDCT shows an SMA embolus and normal bowel in our patient whose condition was discussed in Case 1, catheter-directed treatment can be initiated in the angio suite or hybrid OR without a standard full contrast dose arteriogram. Alternatively, if MDCT shows an SMA embolus and extensive pneumatosis, the patient can be taken directly, without standard arteriography, to the operating room for exploration and SMA embolectomy. Postoperative arteriography could be considered for infusion of papaverine prior to second-look laparotomy.*

MR angiography with gadolinium may be useful in patients with life-threatening contrast allergies or if high-resolution CT is unavailable. Usually these two studies are redundant and it is wasteful of both time and resources to perform both CT and MRI in the patient with suspected AMI.

> Recommendation (Grade 1B): All patients with suspected acute mesenteric ischemia without peritonitis should have a high-resolution abdominal CT scan with contrast and/or a visceral arteriogram. In patients with a life-threatening contrast allergy, magnetic resonance imaging (MRI) should be performed.
>
> Recommendation (Grade 1B): All patients with suspected AMI with peritonitis should have high-resolution CT or MRI. Angiography may also be considered but should not substantially delay operation.
>
> Recommendation (Grade 1A): N-acetylcysteine should be given prior to administration of IV ionic contrast material, and high osmolar contrast agents should be avoided, to decrease the risk of contrast-related renal insufficiency.

WHAT IS THE ROLE OF CATHETER-DIRECTED THERAPY IN ACUTE MESENTERIC ISCHEMIA?

There may be a role for catheter-directed intra-arterial therapy in many patients with acute mesenteric ischemia and it is important that this be discussed by the multidisciplinary team caring for the patient prior to the arteriogram. **Intra-arterial papaverine** infusion is the local treatment of choice for (NOMI).(1, 4) It may also be useful in relieving the vasospasm which can persist after a major thromboembolic arterial occlusion has been successfully treated by open or endovascular technique, or the vasospasm associated with mesenteric venous thrombosis. Thus it may be prudent to leave the transfemoral SMA catheter in place and continue the intra-arterial papaverine infusion for 24–48 h even if the cause of acute mesenteric ischemia is other than NOMI. Papaverine infusion should be considered whether or not there is clinical evidence of bowel infarction.

In patients with acute mesenteric ischemia secondary to thromboembolic occlusion, and no peritoneal signs, **fast-acting thrombolytic agents** may be directly infused via angiographic catheter into the occluding clot.(28–30) In cases of SMA embolism, intra-arterial thrombolysis may be more successful with smaller more distally located minor emboli than with large proximal major emboli. Occlusive atheromatous lesions may be dilated and stented.(31–33) In patients with mesenteric venous thrombosis, thrombolytic agents have been infused with variable success into the SMA, and directly into a portal vein/SMV clot via a transjugular transhepatic route.(34)

Patients with AMI who are treated initially without laparotomy must be followed closely. If abdominal pain does not resolve or worsens, or if peritoneal signs develop, operation is indicated. Laparoscopy may be useful in confusing cases. For patients in whom clinical improvement suggests successful catheter-based therapy, confirmatory MDCT may be prudent prior to initiation of diet and hospital discharge.

> Recommendation (Grade 1A): Administer intra-arterial papaverine for NOMI.
>
> Recommendation (Grade 1C): Consider intra-arterial papaverine for vasospasm associated with acute mesenteric thromboembolism.
>
> Recommendation (Grade 2C): Patients with AMI who do not have peritonitis may be considered for catheter-directed treatment.

OPERATION FOR ACUTE MESENTERIC ISCHEMIA

The goals of operation for acute mesenteric ischemia are to revascularize the bowel and/or to resect the bowel that is clearly irreversibly injured. A midline incision is made and the abdomen is explored. Any leakage of GI contents is controlled and the pattern of intestinal ischemia is assessed. Usually revascularization should be performed before bowel resection. Below the mesocolon, the SMA should be palpated proximally and distally, and the quality of flow in the mesenteric arcades should be assessed. The IMA should be palpated, and the celiac should be assessed by palpation of the hepatic artery and the right gastroepiploic artery.

A sterile Doppler should be used; it may be helpful to compare the quality of Doppler signals in the effected and noneffected vascular beds.

Operation for superior mesenteric artery thromboembolism: The SMA is exposed and controlled in the proximal mesentery below the transverse mesocolon. In general, a longitudinal arteriotomy is probably best since this could be closed with a vein patch or used for anastomosis if SMA bypass is performed. After opening the artery, flow is assessed before and after the gentle passage of embolectomy catheters. If adequate inflow is restored and the distal circulation is cleared of thromboembolic material, the arteriotomy is closed after flushing with papaverine. Patch closure of the arteriotomy may decrease the incidence of thrombosis at the arteriotomy site. If adequate inflow cannot be restored, a retrograde bypass from the iliac artery is the simplest option. Care should be taken to avoid kinking of the graft which may become apparent only when the retractors are removed. Following revasularization, bowel which is unequivocally irretrievable should be resected. Questionably viable bowel should be assessed in 24 h at second look laparotomy. Postoperative therapeutic anticoagulation should be resumed immediately, and consideration should be given to postoperative intra-arterial papaverine infusion. Lifelong anticoagulation may be indicated depending on the clinical scenario. *It should be recognized that with current techniques of home parenteral nutrition and small bowel transplantation, resection of massive lengths of intestine are no longer incompatible with long term survival.*

Operation for nonocclusive mesenteric ischemia: NOMI is best treated nonoperatively, but surgery is necessary for peritonitis or MDCT evidence of bowel infarction in the potentially salvageable patient. The pattern of GI ischemia at operation is variable and often patchy, but there is usually evidence of decreased blood flow in the distribution of all three major mesenteric arteries. Obviously necrotic bowel is resected. Second look operation is done after 24 h of continuous intra-arterial papaverine. It is important to recognize that up to 50% of patients with NOMI may have substantial atherosclerosis of the celiac and/or SMA.

TREATMENT OF MESENTERIC VENOUS THROMBOSIS

Lifelong anticoagulation, and elimination (e.g., oral contraceptives) or identification (e.g., factor V Leiden) of precipitating factors form the basis of treatment for patients with acute mesenteric venous thrombosis. Operation is indicated in patients with peritoneal signs or evidence of bowel infarction on MDCT, the diagnostic test of choice in most patients. Surgical thrombectomy can be considered in special circumstances, for example, postoperative SMV thrombosis. Thrombolytic therapy via SMA infusion (perhaps most useful for mesenteric thrombosis secondary to hypercoagulable states that purportedly start in small vessels) or via transhepatic portography can also be considered.

Recommendation (Grade 2B): Second-look laparotomy should be considered in patients with AMI. This is best performed around 24 h following initial operation.

Ischemic Colitis

CASE 2: A 66-year-old man is admitted to hospital to rule out myocardial infarction. During hemodialysis he experienced a 15-minutes episode of chest pain with associated diaphoresis and hypotension (BP 80/60). Forty eight hours later, serial ECGs and troponin levels are negative for acute MI, but for the past 12 h he has been complaining of left lower quadrant abdominal pain and diarrhea (brown with streaks of blood). The patient had an open abdominal aortic aneurysm (AAA) repair 5 years ago, and has been on chronic hemodialysis for 2 years secondary to chronic renal failure due to hypertension. On examination, pulse is 90/min and regular, BP is 150/90, respirations are 18/min. The patient is mildly uncomfortable and describes the pain as 6 out of 10. The abdomen is mildly distended and bowel sounds are normal. There is moderate left lower quadrant tenderness without signs of peritonitis. Both femoral and dorsalis pedis (DP) pulses are symmetrical but decreased. Hematocrit is 36 and WBC is 16 K/cc. Abdominal obstruction series is unremarkable.

WHAT IS THE PATHOPHYSIOLOGY OF ISCHEMIC COLITIS?

The colon is the abdominal GI organ which receives the least amount of blood per gram of tissue.(35, 36) The colon wall is thicker and the microvascular network is less dense than in the small bowel. These factors and perhaps the intralumenal load of bacteria make the colon quite susceptible to ischemic injury. Normally the right side of the colon receives its arterial blood supply from the SMA via the ileocolic and middle colic vessels, and the left side including the upper rectum is supplied by the inferior mesenteric artery. The distal rectum is supplied by the internal iliac vessels via the inferior and middle hemorrhoidal systems. The marginal artery of Drummond (incomplete in 5% of patients) and the more centrally located arc of Riolan provide collateral circulation. Ischemic colitis usually is segmental or patchy, and reversible. It typically occurs in a "watershed area" (splenic flexure, rectosigmoid, cecum) and more frequently effects the left colon than the right. However any segment of the colorectum may be affected, or the process may be pancolonic. Acute occlusion of the inferior mesenteric artery can lead to profound rectosigmoid ischemia particularly if the SMA is diseased, and/or if the collateral mesenteric vessels are incomplete or poorly developed or surgically interrupted, and/or the internal iliacs are compromised. This occurs around 3–5% of the time after open abdominal aortic aneurysm repair, and has also been reported following endovascular repair.(37) The presentation is within the first few days following surgery.

Most clinically significant cases of ischemic colitis are caused by an acute transient segmental decrease in colonic blood flow to a level below that necessary to meet metabolic demands. This decrease in blood flow may or may not be sustained long enough to create at least mucosal injury, but restoration of flow leads to ischemia reperfusion injury. This can occur during a global

Table 50.3 Risk Factors For Ischemic Colitis.

Hypovolemia
Low cardiac output
Cardiac arrhythmia
Shock
Acute dehydration, eg after marathon running
Mesenteric vascular disease
Colonic distention
  Colonic obstruction
  Colonic ileus
  Volvulus
  Recent colonoscopy or BE\
Vasculitis
Hypercoagulability
Hematologic disease
  Sickle cell disease
  TTP
Aortic dissection
Recent aortic operation
Recent cardiopulmonary bypass
Recent colon operation
Recent mesenteric revascularization
Atherosclerosis/Peripheral vascular disease
Hypertension
Diabetes
Renal Failure
Medication
  Vasopressors
  Digoxin
  NSAIDs
  Antihypertensives
  Diuretics
  Contraceptives
  Estrogen
  Danazol
  Sumatriptan
  Amphetamine
  Cocaine

decrease in mesenteric blood flow, which may have occurred in our patient due to hemodialysis associated hypovolemia, perhaps exacerbated by transient cardiac dysfunction caused by myocardial ischemia. Other associated factors include atherosclerosis, certain medications, hypercoagulability (38), vasculitis, recent cardiopulmonary bypass, increased intracolonic pressure, acute dehydration, and shock (Table 50.3). Usually ischemic colitis does not cause transmural colon infarction or necrosis, and there are not acute occlusions of the named colonic vessels.(39, 40) But sometimes, again usually without major vessel occlusion, the colonic ischemia progresses to infarction and necrosis, and prompt surgical resection is life saving. Certainly acute occlusion of major colonic vessels, either by thrombosis, embolism, or ligation can lead to acute colonic ischemia; these account for a minority of the cases of colon ischemia. Typically this situation occurs in the setting of acute mesenteric ischemia (refer to the earlier sections

of this chapter), or during aortic dissection, or during repair of abdominal aortic aneurysm.

WHAT IS THE DIFFERENTIAL DIAGNOSIS OF ISCHEMIC COLITIS?

Most patients with ischemic colitis are aged over 60 years, and present with acute abdominal pain and diarrhea, often heme-positive. Usually the pain is localized and there is leukocytosis. Peritoneal signs or progressive metabolic acidosis may indicate colonic necrosis. Certainly our patient may have suffered an ischemic insult to his colon yesterday during dialysis. He almost certainly has atherosclerosis, and possibly has chronic IMA occlusion since the AAA repair 5 years ago which can compromise left colon blood flow chronically particularly if the internal iliacs have been compromised by atherosclerosis or previous vascular surgery. The differential diagnosis of ischemic colitis includes diverticulitis, infectious colitis, inflammatory bowel disease, and colon neoplasm. In our patient we must also consider a possible complication related to the AAA repair such as a leaking pseudoaneurysm. The mortality risk in patients hospitalized with ischemic colitis is about 30%.

> Recommendation (Grade 1B): Patients with acute abdominal pain and heme-positive diarrhea, who have appropriate risk factors, should be considered to have ischemic colitis.

WHAT IS THE INITIAL MANAGEMENT OF SUSPECTED ISCHEMIC COLITIS?

The initial management of patients with suspected ischemic colitis includes strategies to optimize colon blood flow and oxygen delivery. Euvolemia should be restored, cardiac function should be optimized, and vasoconstrictors should be discontinued if possible. Supplemental oxygen should be considered. Although there is no evidence to support the use of therapeutic anticoagulation, and such treatment may exacerbate colon blood loss, low-dose heparinoids should be given. Broad-spectrum IV antibiotics should be administered, pending definitive diagnosis, since there are possibilities of "translocation" or perforation. There is no clear role for oral antibiotics or antibiotic enemas. Bowel rest should be initiated.

> Recommendation (Grade 2B): Patients with possible ischemic colitis should be given IV broad-spectrum antibiotics.

WHAT DIAGNOSTIC TESTS SHOULD BE OBTAINED IN PATIENTS WITH SUSPECTED ISCHEMIC COLITIS?

The most useful tests in the patient with suspected ischemic colitis are MDCT scan and colonoscopy.(4, 41, 42) Spiral CT scan should be performed first since it may lead to a different diagnosis (e.g., diverticulitis), or reveal findings which indicate operation and contraindicate colonoscopy (e.g., colonic pneumatosis and

pneumoperitoneum). Segmental circumferential colonic thickening is the most reliable finding for ischemic colitis. The associated mesentery usually has a normal appearance as does the small intestine. Pneumatosis, pneumoperitoneum, and/or new ascites (or abscess) are late signs and usually indicate operation.

In the absence of peritonitis and ominous CT findings, colonoscopy by an experienced endoscopist should be considered next. Minimal air insufflation should be used. Abnormalities are biopsied and the examination is stopped if/when nonviable mucosa is encountered. Suggestive endoscopic findings of ischemic colitis include friability, hemorrhagic nodules, and linear ulceration ("colon stripe sign"). Histopathologic findings include mucosal ulceration or necrosis, and submucosal hemorrhage and edema. Pseudomembranes may be present and clinical differentiation from clostridium difficile colitis can be difficult. If MDCT is unavailable, or if the patient is unable to be transported to the machine, colonoscopy may be considered provided bedside plain X-ray films do not show pneumoperitoneum or pneumatosis. This applies especially to patients within days of abdominal aortic operation who may have rectosigmoid ischemia.

Abdominal ultrasound may occasionally provide useful operation that complements or confirms CT findings in ischemic colitis, but this test is quite operator-dependent and is usually unnecessary. Mesenteric arteriography is also unnecessary unless acute mesenteric ischemia is suspected (see Case 1 earlier). Acute abnormalities of major colonic (named) vessels on arteriography are unusual in ischemic colitis, and there is no documented role for local infusion of papaverine or thrombolytic agents. Plain abdominal X-rays should not be ordered if CT is planned unless the patient has peritoneal signs. There are no serum or blood studies which can reliably rule ischemic colitis in or out. Patients with ischemic colitis should probably be considered for echocardiography and Holter monitor since there is a higher than anticipated likelihood (20–40%) of an associated arrhythmia and/or cardiac clot.(43–46)

> Recommendation (Grade 1B): Patients with suspected ischemic colitis should undergo MDCT scan of the abdomen and pelvis. Colonoscopy and biopsy should also be considered. Cardiology consultation for echocardiogram and Holter monitoring should also be considered.

WHAT IS THE DEFINITIVE MANAGEMENT OF ISCHEMIC COLITIS?

Ischemic colitis usually improves and resolves with supportive management. Initial treatment includes NPO, IV fluid, supplemental O_2, IV antibiotics, prophylactic subcutaneous unfractionated or low-molecular-weight heparin, and serial examinations. When the pain, tenderness, and distention resolve, diet may be resumed. Antibiotics, either IV or oral, should be continued until the patient is afebrile and the WBC is normal.

If the patient deteriorates or develops peritonitis, operation is indicated. Other indications for operation in ischemic colitis are sepsis, failure to improve with medical treatment, stricture, colonic bleeding, and protein-losing enteropathy. Most patients will show substantial improvement after 1 week of medical treatment. Those who have failed to improve in 2 weeks should be considered for operation. Laparoscopy may be considered in equivocal cases but **it is important to recognize that ischemic colitis, severe enough to warrant operation, need not be transmural at all sites**. If resection is considered, all areas of the colon which are deemed abnormal on preoperative imaging, and endoscopy should be resected; these areas may not all appear necrotic or infarcted at the operating room table but leaving them behind is a mistake. Extensive mucosal necrosis with intact muscularis propria (i.e., normal appearing colon in OR) may be just as life-threatening as short segmental transmural necrosis with impending perforation (i.e., black cecum). Total abdominal colectomy is the prudent operation in some patients. Frozen sections of resection margins should be considered. The blood supply of the colon and the small bowel is assessed by inspection, palpation, and portable Doppler. When operation is done emergently or urgently, anastomosis is usually avoided and proximal ostomy with distal mucous fistula or Hartman is preferred.

> Recommendation (Grade 1C): When operation is performed for ischemic colitis, the extent of colectomy must be determined both by findings at operation and by objective preoperative findings (examination, CT, endoscopy). In certain cases, total abdominal colectomy may be preferable to segmental resection. Frozen section examination of resection margins is recommended.

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51 Acute cholecystitis

Adam D Fox and John P Pryor†

A 52-year-old African American male presents to the emergency department with 3 days of fever, right upper quadrant (RUQ) pain, and scleral icterus. His past medical history is only significant for sickle cell anemia, does not take any medication, has never had any surgery, and no known allergies. On a review of systems, it is found that he has been experiencing intermittent RUQ pain for several months. Physical examination reveals that he is a well-developed male who is mildly tachycardic. Scleral icterus is present along with a tender RUQ and associated Murphy's sign.

Ultrasound (US) examination demonstrates gallbladder wall thickening, multiple small gallstones, and a common bile duct measuring 1.3 cm. The PT is also found to have an elevated white blood cell (WBC) count of 12,000, bilirubin of 4, Amylase of 80, and a normal lipase.

Figure 51.1 Ultrasound evidence of acute cholecystitis.

Cholelithiasis is the etiologic agent of acute cholecystitis (AC) over 90% of the time. As the stones cause obstruction of the cystic duct, the resultant buildup of bile leads to gallbladder distention and edema. If the obstruction persists, inflammation and edema continue eventually leading to ischemia and necrosis (Figure 51.1).

Gallstones result from an inability to maintain the normal balance between the key elements of bile solutes. Stone formation will then be dependent on which elements predominate. In the United States, cholesterol stones are found in 70–80% of the population with a prevalence rate of 10–15% in the United States and Europe.(1, 2) The remainders are pigment stones which can then be classified brown or black.

An estimated 30 million Americans have gallstones with more than 750, 000 requiring cholecystectomy each year. The costs for this disease process is placed between $8 billion and $10 billion annually.(3)

Although women tend to have a higher frequency of gallbladder disease, the female to male ratio closes with advancing age. Cholecystectomies are rarely performed in the population under age 20.(4, 5) Several other risk factors have been implicated and may predispose the patient to gallstones. These include age, race, obesity, diabetes, hemolytic disease, parity, and genetics.(6, 7)

Only about 30% of patients with asymptomatic gallstones will need surgery. There are however several factors that predict a more serious course and may warrant prophylactic cholecystectomy. These include patients with large gallstones and hemolytic anemias.(8)

In addition to AC, ascending cholangitis and gallstone pancreatitis represent other biliary tract emergencies that may be encountered in the acute setting. Both ascending cholangitis and gallstone pancreatitis result from biliary obstruction with the duration of obstruction determining its course and severity.

Acute acalculous cholecystitis (AAC) is the clinical entity where acute inflammation of the gallbladder exists without cholelithiasis. It typically occurs in patients with critical illness. Often, the patient is one who has been immobile, fasted for prolonged periods, and been hemodynamically unstable. Without stones to cause obstruction, the presumed pathogenesis is multifactorial with gallbladder paresis, ischemia, and stasis all playing a role.(9)

WHAT ARE THE CLINICAL SYMPTOMS AND SIGNS ON PRESENTATION?

The typical patient with AC will present with RUQ pain associated with nausea, vomiting, and fever. The pain can be midepigastric and radiate to the back, right scapula, or shoulder region. Upwards of three quarters of AC patients will report a previous history of biliary colic.(10) These two entities can usually be distinguished based on duration of symptoms and presence of Murphy's sign. (9) A positive Murphy's sign has been found to be highly sensitive (97%) and predictive (positive predictive value 93%) of AC.(11) It should be noted that disease presentation in the elderly may not be typical with the absence of RUQ pain and a possibility of fever.

Patients with ascending cholangitis may present with a spectrum of disease that ranges from a mild self-limiting process to a severe life-threatening condition. The classic triad of fever, RUQ pain, and jaundice attributable to Charcot occurs in 56–70% of patients with cholangitis.(12) A more severe form described by Reynolds added hypotension and altered level of consciousness to the Charcot description but is only seen 5–7% of the time.(13,

14) Ultimately, fever is the most common symptom but the presence of ascending cholangitis is suggested if along with fever a leukocytosis and abnormal liver function tests are present.

Patients with gallstone pancreatitis will often present (~50%) with a sudden onset of unrelenting upper abdominal pain that radiates to the back. Nausea and emesis frequently accompany the pain.

AAC can present with the same signs and symptoms as AC but more often these will be absent. Pyrexia may be the only presenting sign and upwards of 75% of cases may not even have RUQ symptomatology.(9)

WHAT ARE THE PERTINENT DIAGNOSTIC STUDIES?

Other than an elevated WBC count, there are no specific lab tests that are useful in diagnosing AC. As the disease process progresses from the gallbladder and involves the biliary tree, as in ascending cholangitis, elevated liver enzymes may be seen. Bile cultures will be positive in 80–100% of patients with ascending cholangitis and a positive blood culture may be found in 20–71%. Those with gallstone pancreatitis will have elevated liver enzymes along with elevations in the amylase and lipase. An ALT (rise more than three times the upper limits of normal within 1–2 days of onset has a positive predictive value of 95% for gallstone pancreatitis.(15) Elevated serum amylase and/or lipase three times normal is also highly diagnostic of gallstone pancreatitis, however, the level of elevation does not correlate with severity of the disease. Additional lab studies to be considered for gallstone pancreatitis are triglyceride and calcium levels.

US should be the initial study in those presenting with suspected gallbladder or biliary disease. It is easy to perform, easily reproducible, and sensitivities approach 90–95%. US findings suggestive of AC are summarized in Table 51.1. It should be noted that gallbladder wall thickening, pericholecystic fluid, and tenderness in the region of the gallbladder when examined with an US probe are all nonspecific findings, and more than 50% of patients with AC will not have wall thickening.(16)

Although often performed, computed tomography (CT) scans should not be the initial study employed for diagnosis of AC. Findings suggestive of AC on a CT scan are thickened gallbladder wall, pericholecystic fluid collection, enlarged gallbladder and linear densities in the pericholecystic fat tissue.(17) If an US is not diagnostic, a hepatobiliary iminodiacetic acid (HIDA) scan should be used. A nonfilling gallbladder after 60 minutes indicates cystic duct obstruction and gives an 80–90% sensitivity for AC.(18) There is a false-positive rate of 10–20% that is usually due to cystic duct obstruction secondary to chronic inflammation. When the gallbladder fills within 30 minutes, the false-negative rate of this exam is 0.5% which increases to 15–20% if filling takes between 30 minutes and 4 h.(18) HIDA scan does have a higher specificity and accuracy when compared to US but because of the ease of use, US is favored. There is no current role for the oral or intravenous cholecystogram in the diagnosis of AC.(19)

Recently, guidelines were published that provide diagnostic criteria for AC. The Tokyo Guidelines, as they have become known, provide criteria for both diagnostics as well as severity.(17, 20) The diagnostic criteria call for an evaluation of local signs of

Table 51.1 Sonographic Findings Suggestive of Acute Cholecystitis.

Gallbladder wall greater than 3–5 mm
Gallbladder distention (long axis > 8 cm, short axis diameter >4 cm)
Pericholecystic fluid
Sonographic Murphys sign
Sonolucent layer in the gallbladder wall

Table 51.2 Diagnostic Criteria for Acute Cholecystitis.

A. Local signs of inflammation, and so on:
  (1) Murphy's sign, (2) RUQ mass/pain/tenderness
B. Systemic signs of inflammation, and so on:
  (1) Fever, (2) elevated CRP, (3) elevated WBC count
C. Imaging findings: imaging findings characteristic of acute cholecystitis
Definite diagnosis
  (1) One item in A and one item in B are positive
  (2) C confirms the diagnosis when acute cholecystitis is suspected clinically

Note: Acute hepatitis, other acute abdominal diseases, and chronic cholecystitis should be excluded.

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Table 51.3 Criteria for Mild (Grade I) Acute Cholecystitis

"Mild (Grade I)" acute cholecystitis does not meet the criteria of "severe (Grade III)" or "moderate (Grade II)" acute cholecystitis. Grade I can also be defined as acute cholecystitis in a healthy patient with no organ dysfunction and only mild inflammatory changes in the gallbladder, making cholecystectomy a safe and low-risk operative procedure.

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Table 51.4 Criteria for Moderate (Grade II) Acute Cholecystitis.

"Moderate" acute cholecystitis is accompanied by any one of the following conditions:
1. Elevated WBC count (18,000/mm^3)
2. Palpable tender mass in the right upper abdominal quadrant
3. Duration of complaints 72 h
4. Marked local inflammation (biliary peritonitis, pericholecystic abscess, hepatic abscess, gangrenous cholecystitis, emphysematous cholecystitis) a Laparoscopic surgery in acute cholecystitis should be performed within 96 h after the onset (Level 2b–4)13,14,1

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inflammation, systemic signs of inflammation, and imaging studies (Table 51.2). Criteria for severity use a grading system that distinguishes mild/Grade I, moderate/Grade II, and severe/Grade III (17) (Tables 51.3–51.5) Limitations of these criteria are with underdiagnosis if the patient exhibits few systemic symptoms and that C-reactive protein levels are not typically obtained in the United States.(18)

Imaging for ascending cholangitis is similar to that used for AC. The transabdominal US is the most commonly used initial study. It has a low sensitivity but high specificity for detection of common duct stones. Indirect findings such as presence of gallstones

Table 51.5 Criteria for Severe (Grade III) Acute Cholecystitis.

"Severe" acute cholecystitis is accompanied by dysfunctions in any one of the following organs/systems

1. Cardiovascular dysfunction (hypotension requiring treatment with dopamine ≥5 mcg/kg/min, or any dose of dobutamine)
2. Neurological dysfunction (decreased level of consciousness)
3. Respiratory dysfunction (PaO_2/FiO_2 ratio < 300)
4. Renal dysfunction (oliguria, creatinine > 2.0 mg/dl)
5. Hepatic dysfunction (PT-INR > 1.5)
6. Hematological dysfunction (platelet count < 100,000/mm³)

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Table 51.6 Diagnostic Criteria for Acute Cholangitis.

A. Clinical context and clinical manifestations
   1. History of biliary disease
   2. Fever and/or chills
   3. Jaundice
   4. Abdominal pain (RUQ or upper abdominal)

B. Laboratory data
   5. Evidence of inflammatory response a
   6. Abnormal liver function tests b

C. Imaging findings
   7. Biliary dilatation, or evidence of an etiology (stricture, stone, stent, etc.)
   Suspected diagnosis: two or more items in A

Definite diagnosis (1) Charcot's triad (2 3 4)
(2) Two or more items in A both items in B and item C
   a. Abnormal WBC count, increase of serum CRP level, and other changes indicating inflammation
   b. Increased serum ALP, r-GTP (GGT), AST, and ALT levels

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or ductal dilatation are suggestive of the diagnosis. It should be pointed out however that with an acute obstruction, the common bile duct may not be dilated. CT scan for the detection of biliary stones has a similar low sensitivity but is useful in detecting ductal dilatation and the presence of other pathology such as liver abscess. Magnetic resonance cholangiopancreatography (MRCP) and endoscopic US are reasonably good at detecting stones and are less invasive than the standard endoscopic retrograde cholangiopancreatography (ERCP).

As part of the Tokyo Guidelines, criteria were assembled for acute cholangitis. Table 51.6 shows that the diagnosis is broken down based on clinical context/manifestations, laboratory data, and imaging findings. When applying these criteria one can make a suspected or definitive diagnosis based on how many criteria are met.(20) These guidelines also created severity assessment criteria for cholangitis. Table 51.7 shows that mild, moderate, and severe grades exist based on organ dysfunction and response to treatment.

Table 51.7 Definitions of Severity Assessment Criteria for Acute Cholangitis.

Mild (Grade I) acute cholangitis
"Mild (Grade I)" acute cholangitis is defined as acute cholangitis which responds to the initial medical treatmentª
Moderate (Grade II) acute cholangitis
"Moderate (Grade II)" acute cholangitis is defined as acute cholangitis that does not respond to the initial medical treatmentª and is not accompanied by organ dysfunction
Severe (Grade III) acute cholangitis
"Severe (Grade III)" acute cholangitis is defined as acute cholangitis that is associated with the onset of dysfunction at least in any one of the following organs/systems:

1. Cardiovascular system Hypotension requiring dopamine _5 ⌠g/kg/min, or any dose of dobutamine
2. Nervous system: Disturbance of consciousness
3. Respiratory system: PaO_2/FiO_2 ratio < 300
4. Kidney Serum creatinine > 2.0 mg/dl
5. Liver PT-INR > 1.5
6. Hematological system Platelet count < 100,000/⌠l

Note: Compromised patients, e.g., elderly (> 75 years old) and patients with medical comorbidities, should be monitored closely
a. General supportive care and antibiotics

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The transabdominal US is again the initial imaging study used when gallstone pancreatitis is suspected. While the US does not necessarily image the pancreas well, it provides information about the presence of stones and ductal dilatation. A contrast-enhanced CT scan is the best tool for evaluation of the pancreas, both for the parenchyma and peripancreatic tissue. Additionally, the CT scan will provide other information that may identify other causes for the patient's presentation. The MRCP provides comparable reliability to the CT scan in evaluation of severity and local complications but also allows for identification of hemorrhage, necrosis versus fluid collection, and bile duct stones. Finally, endoscopic US has some utility in detecting biliary stones. This can be used as a less-invasive method prior to utilizing ERCP.

If AAC is suspected, an US should be performed. Similar findings to those in AC are expected except for lack of stones. US sensitivity in AAC has been reported to be between 29% and 92% with a specificity being over 90%.(21, 22) The HIDA scan is sensitive but lacks specificity because the patient has frequently been nil per os (NPO), with resultant biliary sludge . The HIDA scan often becomes complimentary to the US.

TREATMENT OPTIONS AND CONTROVERSIES
The initial management for AC is admission to the hospital where the patient is to be made NPO, and started on IV fluids, analgesics, and antibiotics, along with consideration of nasogastric decompression should persistent nausea and vomiting occur. The choice of antibiotic is usually dictated by local protocol but coverage of the usual bacterial flora found in the gallbladder should be employed. Gram-negative aerobes (i.e., Enterobacteriaceae family) make up the majority of bacteria however some Gram-positive

and anaerobic coverage should be provided. A course of 3 days has been shown in head-to-head studies as efficacious to longer treatment times (23) Although not employed, there has been some literature to support the use of nonsteroidal anti-inflammatory drugs (NSAIDs) to help slow or reverse the inflammatory changes that occur with AC.(24, 25)

Ultimately, the gold standard of treatment for AC is cholecystectomy. This had been accomplished with an open approach until the late 20th century. The laparoscopic approach had initially been used for elective gallbladder surgery, but as the skill and comfort level with the procedure grew, it was employed for AC. There is a clear literature supporting the use of the laparoscopic cholecystectomy (LC) in the setting of AC. Initial reports of its success were published in the early 1990s.(26, 27) A review of a 10-year experience with LC in AC with over 1,000 patients showed that LC is "safe and effective for AC."(28)

The largest controversy regarding treatment of AC is in the timing of the procedure. Several studies have demonstrated that early open procedures were superior to delayed operative intervention.(29, 30) With the introduction of laparoscopic surgery for AC, it became less clear as to the optimal timing. The "cooling off" period was revisited as a means to help reduce the concerns over proper identification of the operative anatomy as inflammation progresses. Studying the optimal timing for a laparoscopic approach has been made difficult by the various definitions of "early" operative intervention. Ranges studied vary from 24 h to 7 days. Complicating factors has been identifying at which point the timing is measured, from symptom onset or time of presentation.

What is clear, even if the definition of early is not found, is that the laparoscopic approach at some point early in the disease state is the preferred method for most patients.(31–40) The window of opportunity seems to be upwards of 7 days from admission. (41) Finally, A Cochrane Collaboration® review found that "early laparoscopic cholecystectomy during AC seems safe and shortens hospital stay."(42)

Despite this, the evidence does suggest that with increased duration of symptoms, a higher conversion rate to open cholecystectomy does occur.(43) Therefore, the most prudent action would be to perform a LC at the earliest possible time from admission with a diagnosis of AC. Once reaching a point past 72 h, the LC can be performed but with the understanding that a more skilled laparoscopist be available and the threshold for conversion to an open procedure be low if the anatomy cannot be discerned and the procedure cannot be performed safely in a reasonable period of time, usually translating to 2–3 h. There is also some suggestion based on the severity scoring developed in the Tokyo Guidelines that moderate and severe forms be treated with gallbladder drainage.(44) This would allow the overall condition of the patient to be stabilized after which an interval LC could be performed.

There have been multiple studies with conflicting conclusions that try to suggest the patient profile with the greatest risk for conversion to an open procedure. Several variables have been used that include duration of symptoms > 72–96 h, age > 60 years, WBC count > 18,000, male gender, low serum albumin, diabetes mellitus, and elevated total bilirubin.(45–47) The most

Table 51.8 Technical Aspects of Laparoscopic Cholecystectomy (Adapted from SAGES).

Identify cystic duct at junction with gallbladder

Traction of the gallbladder infundibulum should be lateral rather than cephalad

Meticulous dissection of cystic duct and artery

Energy source can contribute to occult injury

Perforations of gallbladder should be controlled to prevent loss of stones

Spilled stones should be removed if possible and irrigation is useful for small stones and bile

Biliary tract imaging should be applied liberally

Conversion to open operation for unresolvable technical difficulties or anatomic uncertainties/anomalies

important factor may be the surgeon's understanding of the natural course of the disease process, combined with an honest intraoperative appraisal of the inflammation and anatomy.

As suggested in the Tokyo Guidelines, there will be patients with a severe form of the disease who will need stabilization prior to surgical intervention. These patients are ideal candidates for a temporary drainage procedure. Percutaneous cholecystostomy (PC) performed under radiologic guidance has a high technical success rate, low complication rate, and high resolution rate.(48) Even with the success rate of the PC, there may not be a difference in outcome between PC and conservative management.(49) Technical points concerning the technique of LC in the setting of AC have been set forth by the Society of American Gastrointestinal and Endoscopic Surgeons (SAGES).(50) (Table 51.8)

Another feasible option in a severely inflamed gallbladder is the subtotal cholecystectomy. The procedure includes only partial removal of the gallbladder, with the posterior wall and neck left in place without resection. It is considered when performing surgery in patients with severe cirrhosis or coagulopathy where dissecting the gallbladder wall off the liver bed can lead to significant bleeding. In addition, it may be considered in patients with severe inflammation in the gallbladder neck cystic duct junction to prevent injury to the common bile duct or hepatic arteries. Although only small cohorts of patients have been examined, it appears to be a relatively simple and definitive procedure that may eliminate the need for cholecystostomy or conversion to open procedure.(51)

Among the many controversies that continue in emergent biliary surgery is the management of concomitant choledocholithiasis. As the optimal treatment for gallstones has evolved so to have the management of common bile duct stones (CBDS). When the open cholecystectomy was the operative choice, common duct explorations were standard and the use of perioperative ERCP was limited. With the transition to LC along with its learning curve, the ERCP, whether used pre- or postoperatively, has become common management for CBDS. The technical aspects along with the need for specialized equipment made the ERCP a very attractive choice for clearance of CBDS.

With improving laparoscopic skills and the ability to perform a laparoscopic common duct exploration conversations about the need for ERCP are valid yet again. Additionally, the use of

Table 51.9 Options for Common Bile Duct stones.

	PRE-OP	INTRA-OP	POST-OP
OPTION 1	ERCP±SPHINCTEROMY	NONE	NONE
OPTION 2	NONE	IOC	NONE
OPTION 3	NONE	IOC+CBDE	NONE
OPTION 4	NONE	IOC	ERCP
OPTION 5	NONE	IOUS±CBDE	ERCP

ERCP = Endoscopic retrograde cholangiopancreatography.
IOC = Intraoperative cholangiogram.
CBDE = Common bile duct exploration.
IOUS = Intraoperative ultrasound.

intraoperative US for identification of both the anatomy and the stones has gained traction.(52–54) A review by the Cochrane Collaboration titled "Surgical versus endoscopic treatment of bile duct stones" found: "open bile duct surgery is superior to open cholecystectomy plus ERCP and that laparoscopic bile duct clearance is proving to be as safe and efficient as ERCP in achieving bile duct clearance. In fact, in the endoscopy arms of the studies examined, more procedures and longer hospital stays were found."(55)

In the end, with the multiple possibilities that exist, the ultimate approach to CBDS found at the time of LC should depend on the skill set of the operating surgeon along with the resources available.(50) (Table 51.9) Several parameters have been described to guide an approach that predominantly deals with size and number of stones. Extremely small stones < 3 mm may be amenable to observation, stone up to 7–8 mm can be handled via transcystic approach. Sizes greater than this and/or multiple stones will likely require choledochotomy and laparoscopic duct exploration if the size of the duct is amenable.(50, 56) An intraoperative cholangiogram should be performed whenever there is doubt as to the anatomy or if there is suspicion of common duct stones. Alternatively, intraoperative US can be performed.

The management of ascending cholangitis is predicated on the severity of the illness. The overall management scheme should be a combination of medical therapy, antibiotics, and biliary decompression. The urgency of biliary decompression should be dependant on the severity of the illness. Medical support consists of hydration and correction of metabolic derangements and coagulopathies. Antibiotics should be started as early as possible when the diagnosis of ascending cholangitis is entertained. The choice of drug will be based on several factors but in general, broad-spectrum antibiotics with adequate biliary excretion such as ampicillin/sulbactam, piperacillin/tazobactam, quinolones, third and fourth generations of cephalosporins, and carbapenems are appropriate. Those patients who may be immunosuppressed, elderly, or had previous biliary surgery with or without a stent should have anaerobes covered. The duration of therapy will be based on the patient's clinical response. For mild disease, therapy for 5–7 days is appropriate. Patients who have a positive blood culture should be continued on antibiotics for 10–14 days. (57) Biliary drainage can be accomplished in several different ways. Endoscopic biliary decompression should be used in severe

cholangitis. In these instances, decompression by ERCP has a lower morbidity and mortality than with open surgery in which bile duct exploration is performed.(58, 59) Other options for decompression are the percutaneous transhepatic cholangiography (PTC) drain. This has a success rate of 95–98% in those with ductal dilatation. This should be used in those with contraindication or failed endoscopic drainage. The last potential option for drainage is with laparoscopic or open common duct exploration. Because there is an associated morbidity, it is rarely performed as the initial procedure. Rather, it is reserved for failure of both endoscopic and percutaneous drainage procedures.

As with the other disease entities, the management of gallstones pancreatitis should begin with intravenous hydration, correction of metabolic derangements, and prevention of hypoxia. Nasogastric decompression should be employed if nausea and significant ileus are present. Pain management should be employed as needed. A low threshold should be given to admission to an intensive care unit. Nutritional support should be initiated as soon as possible. The parameters guiding this will depend on the severity of the disease. In mild pancreatitis, oral intake can be started once clinical improvement is noted. In those patients with severe pancreatitis, early enteral feeding has been shown to be safe.(60) Jejunal feeding had been a standard when employing enteral nutrition, but studies have shown that gastric feeding is tolerated and safe.(61) Prophylactic antibiotic usage for anything other than an infected pancreatitis is not recommended.(62)

Specific therapy for gallstone pancreatitis begins with stone clearance. Because patients with mild to moderate disease usually have spontaneously passing stones, ERCP is not required. For severe pancreatitis, an urgent ERCP should be employed. Because the source of the obstructing stone is usually the gallbladder, a cholecystectomy should be performed during the same hospitalization or within 2–4 weeks from discharge because delay results in a high likelihood of recurrent pancreatitis.

WHAT ARE THE CHALLENGES OF ACUTE CHOLECYSTITIS IN PREGNANCY?

The pregnant woman is predisposed to gallbladder disease. The hormonal changes that occur with pregnancy increase gallbladder volume both during fasting states and after meals, thereby increasing the saturation of bile with cholesterol along with a decrease in the circulating bile salt pool. Gallstones are present in ~5% of the pregnant population but are often asymptomatic. (63) Less than 0.05% will develop symptomatic cholelithiasis and ~ 40% of those will require surgery.(64)

The initial management of a pregnant woman should mimic the nonpregnant patient. Admission to the hospital, bowel rest, intravenous fluid, appropriate analgesics, and antibiotics should be initiated for patients with AC. Because of the hesitancy to operate on the pregnant patient, medical management has been the preferred option. However, ~ 41% of women fail a nonoperative approach and require a cholecystectomy.(65) There are some authors who do however recommend surgery over nonoperative management for a pregnant woman in her second trimester. (66) Regardless of the trimester however, any deterioration in the patient while being managed nonoperatively should prompt a cholecystectomy.(67)

There have been multiple studies demonstrating epidemiologic factors related to surgery in pregnant woman. During the first trimester, the major risks of operation are related to teratogenesis and carry a miscarriage rate of ~ 12%. Operation during the third trimester carries with it a 30% rate of preterm labor and premature delivery. Unlike the other trimesters, the second trimester carries with it a very low miscarriage rate and a preterm labor risk of 5–8%. Additionally, there is no risk for teratogenesis, and the gravid uterus does not create problems with exposure.(63)

The indications to operate on a pregnant patient with biliary disease are: (1) repeated attacks, (2) AC, (3) persistent vomiting, and (4) gallstone pancreatitis. As mentioned earlier, the ideal time for intervention is the second trimester.

Once this decision is made, the next question that must be addressed is about the approach.

Because a cholecystectomy will be required in 40% of pregnant woman with symptomatic biliary disease, it is imperative to understand the implications of surgery in this patient population. Uncomplicated open cholecystectomy has been associated with a 0.1% maternal mortality rate, 5% prevalence of fetal death, and a 7% prevalence of preterm labor and premature delivery. (63) With a reasonable safety record, the open cholecystectomy was unquestionably the procedure of choice in this population. That however has changed with the ever-increasing experience with the LC. Just as in the nonpregnant patient population, the indications for LC have been significantly broadened since the beginning of its use. Pregnancy is no longer a contraindication to its use.

Similar to the nonpregnant patient, the LC carries with it the same advantages in the pregnant woman. A faster recovery means shorter hospital stays and lower costs. Fewer postoperative adhesions are associated with the laparoscopic approach. There is earlier postoperative mobilization which reduces the thromboembolic risk which is greater in the pregnant population. Because of the decreased pain, fewer narcotics are used. There is an earlier return to a regular diet which is beneficial for the pregnant woman. Finally, there is less uterine manipulation with a laparoscopic approach resulting in a decreased risk of preterm labor.

As one might imagine, some disadvantages do apply to the laparoscopic approach. The biggest question comes with CO_2 pneumoperitoneum. There is currently no research as to the effects of increased abdominal pressure and effects of CO_2 on humans. It is thought to affect the fetus by directly increasing pressure on the uterus and altering maternal hemodynamics along with acid–base status. Several animal studies have demonstrated a severe fetal acidosis associated with CO_2 pneumoperitoneum (68) Despite the intraoperative changes, one study investigating long-term effects of CO_2 pneumoperitoneum on pregnant ewes found that all ewes delivered full-term, healthy lambs suggesting that short-term fetal acidosis may not lead to deleterious effects.(69) Although there are no specific studies addressing these deleterious effects in the human population, laparoscopy in early pregnancy is well established in the gynecologic literature.

The first LC for gallbladder disease in the pregnant patient was performed in the early 1990s through June, 1999; 46 reports were found in the literature, most performed during the second trimester. Other than one report of maternal–fetal death 15 days after the procedure, no other cases of maternal–fetal complications were reported.(70) A total of six fetal deaths have been reported with a gestational age of between 12–15 weeks but without official causation.(63) A review of the literature in 1998, showed that in all three trimesters, the rates of premature delivery or spontaneous delivery were equal or less when compared with open cholecystectomy.(71)

As with all surgical interventions, attention to detail will help eliminate some potential problems. The patient should be placed in a left lateral position to help offload the inferior vena cava and allow better venous return. DVT prophylaxis should be used along with the appropriate preoperative antibiotics. Although anesthesia may bring a special risk in this patient population, careful attention to positioning will not only help augment venous return but help reduce the chances of aspiration. This can also be accomplished by the standard placement of a naso or orogastric tube. The use of nitrous oxide and sedatives should be avoided. There is even a report that an epidural strongly be considered for this particular procedure.(72) Because of the acidosis that is known to occur, recommendations are for continuous end tidal carbon dioxide monitoring maintaining levels between 25–33 mm. Maternal respiratory acidosis should be promptly corrected by way of changing minute ventilation.

There seems to be a general agreement that a Hasson technique be employed for entry into the abdomen. Should a Veress needle be used, alternate locations (i.e., left upper quadrant [LUQ]) should be employed for abdominal access. Despite the potential for increased injury with a "blind" entry, a review of 20 cases reported no complications.(63) Other than placing the umbilical port in a supraumbilical position, port placement is essentially the same as the nonpregnant patient. It should be noted however that as gestational age increases the ports may need to be moved to more cephalad positions. Once access has been obtained, intra-abdominal pressures should remain high enough to maintain a satisfactory pneumoperitoneum (10–12 mmHg) but should not exceed 15 mmHg. Some recommend an angled scope for better visualization. As always, conversion to an open approach should be used if the anatomy cannot be identified safely.

Controversy exists regarding the need for intraoperative fetal monitoring. Recommendations abound from intraoperative monitoring as early as 6-weeks gestation (to see how pneumoperitoneum affects the fetus) to just pre- and postoperative evaluations. Still others, recommend monitoring only postoperatively in the late second and third trimesters. Regardless, transvaginal monitoring is the preferred approach because it does not interfere with an intra-abdominal surgery nor will its image be distorted by the pneumoperitoneum.

Intraoperative cholangiography should be performed as needed but there is enough literature to suggest that there were no retained stones in patients with suggestion of stones in the biliary system. The risks of the cholangiography are due to the radiation. If it is to be employed, the fetus should be shielded as best as possible. Other options to image the biliary tree include intraoperative ultrasonography, transcystic duct choledochoscopy, and endoscopic papillotomy.

There is no evidence to support prophylactic tocolytics but they should be employed if uterine irritability or contractions occur.

Table 51.10 Evidence-Based Recommendations for Biliary Disease.

Recommendation	Reference	Grade
Laparoscopic versus open cholecystectomy for acute cholecystitis	26, 27, 28	1A
Timing of laparoscopic cholecystectomy (early vs. late)	29–43	1B
Surgical (laparoscopic) versus endoscopic treatment of common bile duct stone (favoring surgical)	52, 55	1B
Gastric feeding of gallstone pancreatitis	61, 62	1B/1C
Laparoscopic cholecystectomy in pregnancy	70, 71, 72	1C

While the pregnant patient creates a special situation, attention to detail should create a safe environment in which the patient can be treated. LC should now be considered the first choice of operative intervention. Proper positioning, careful anesthetic monitoring, and avoiding a prolonged case will all lead to better outcomes.

SUMMARY

AC and associated biliary diseases represent a fairly common problem for the acute care surgeon (Table 51.10). As for any disease process, a thorough understanding of the pathophysiology of the disease is necessary. RUQ pain links many of these diseases. Duration of symptoms will help delineate the acute process. Once suspicion is high, the appropriate testing usually includes basic labs and liver functions testing along with a RUQ US. If a diagnosis of AC is made it becomes important to determine how difficult the surgery will be. If the duration of the disease process is prolonged, understanding that a laparoscopic approach may not be feasible is important for both the surgeon and the patient. This scenario however should not deter an initial laparoscopic attempt but with an understanding that conversion to an open procedure may be necessary.

Finally, special populations such as the pregnant patient should be the cause for pause and extra planning but should not deter the appropriate care.

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52 Acute pancreatitis
Pamela A Lipsett

A 58-year-old male with known alcohol abuse, admitted several times for pneumonia and hemorrhagic gastritis, now presents with midepigastric pain radiating to the back. He has a temperature of 102°F; WBC of 15 K, elevated serum glutamic oxaloacetic transaminase (SGOT) and serum glutamic pyruvic transaminase (SGPT) in the 100s. Amylase is 105 and lipase is 250. A dynamic phase computed tomography (CT) scan with 0.5-mm cuts and intravenous (IV) contrast demonstrated pancreatic necrosis, but no abscess or peripancreatic fluid. The patient was admitted to the intensive care unit (ICU) with systemic inflammatory response syndrome (SIRS) for IV antibiotics, IV hydration, and nasogastric (NG) tube. The patient's condition did not improve, and repeat CT scan demonstrated more necrosis and peripancreatic fluid. CT-guided aspiration revealed gram-negative rods, and the patient was taken to the operating room for wide debridement versus marsupialization.

ACUTE PANCREATITS: GENERAL OVERVIEW

What Is the Epidemiology and Demongraphics of Patients with Acute Pancreartitis?

Patients with acute pancreatitis (AP) can present with a wide degree of severity of illness, from the very mild presentation with epigastric pain and mild nausea, to a severe form of pancreatitis with alterations of vital signs, high fevers, tachycardia, hypotension from intravascular volume depletion, or respiratory embarrassment.(1–3) While the latter description is much like the patient presented earlier, patients with severe AP account for approximately 20% of all patients who present with AP.(1, 3) Patients with severe acute and often necrotizing pancreatititis typically require intensive monitoring, and often intensive care interventions. On the other hand, patients with the milder form of AP may not even require admission to the hospital. This less ill group of patients is easily recognizable to the experienced clinician. When considering all patients who present with AP, the overall mortality is about 1.5 deaths/100,000 person years.(1) While the overall incidence of AP does vary between and within countries, the incidence of this disease overall is about 16–40 per 100,000 patients.(1, 3) In some countries, such as Scotland, the incidence of AP has been increasing.(3, 4) The specific reason for this increase is not known.

AP is slightly more common in men (1.2–1.5) than in women, but this demographic depends on geographic location and also on the etiology of the disease. In particular when the etiology of the disease is related to biliary stones, then AP is more common in women.(4) However, when the etiology of the disease is alcohol, such as in the patient presented earlier, the disease is more common in men. While alcohol is believed to be the most common etiology of AP in the United States, worldwide biliary disease accounts for 45% of all cases. Because the provider may take action to intercede with a procedure to remove stones from the biliary tree, if the patient is severely ill with AP, this etiology should at least be theoretically considered in all patients.(5) An ultrasound (US) should be used liberally when a question about this possibility arises.

Traumatic injury of the pancreas can be a cause of pancreatitis. Trauma from a surgical procedure or post-endoscopic retrograde pancreatocholangiography (ERCP) can injure and inflame the pancreas. Trauma from compression of the pancreas against the vertebral column from a forceful ventral–dorsal compression, such as can occur from a handlebar injury, surf board, or karate kick to the upper abdomen, should heighten awareness of these possible mechanisms of injury. Many other possible etiologies for AP exist, but these are uncommon (4) (Table 52.1). Nonetheless, the practioner should be aware of these more unusual etiologies when the more common etiologies of AP have been excluded. For example, if the most likely etiologies have been considered and excluded, a careful drug history should be obtained, as well as a family history, and exposure to possible bites (spiders, scorpions, and the Gila monster). The laboratory profile may provide a clue about cause of AP through the presence of hypercalcemia (that hyperparathyroidism is a possible etiology), or that hypertriglyceridemia may be a causative factor. The role of biliary sludge, pancreatic duct abnormalities such as a pancreatic divisum, and sphincter of Oddi dysfunction in the development of AP is less clear.(6)

At least three genetic polymorphisms appear to play some role in pancreatitis; cationic trypsinogen gene (PRSS1) mutations (hereditary pancreatitis), cystic fibrosis transmembrane conductance regulator (CFTR) mutations (idiopathic chronic pancreatitis), and serine protease inhibitor, Kazal Type 1 (SPINK1) mutations (modifier of severity of disease) all have some role.(7, 8, 9) These genes or gene products account for the vast majority of currently identifiable predisposition to AP. They are seen in the hereditary form and are not clearly linked to the alcoholic form. The PRSS1 mutation is most closely linked to the hereditary form of pancreatitis. With this mutation, the site where autolysis occurs has a single mutation, and thus trypsinogen is activated to trypsin in the acinar cell and has a prolonged survival causing cell damage and AP.(7)

CLINCIAL PRESENTATION

Symptoms, Signs, and Laboratory Evaluation

The vast majority of patients with AP will present with upper abdominal pain, often radiating through into the upper mid-back.(2, 10, 11) They will have had nausea and vomiting as a

Table 52.1 Common Etiologies for Acute Pancreatitis.

Gallstones

Alcohol

Trauma

Post-procedure: ERCP, cardiac or abdominal surgery

Pancreatic/common bile duct obstruction:
Choledochal cysts, annular pancreas, duodenal diverticulum, Crohn's disease, tumor

Bites: scorpion, spider, Gila monster

Hereditary/genetic :
SPINK, CFTR, PRSS1

Hypercalcemia

Hyperlipidemia

Toxins: organophosphates

Drugs*: azathioprine, pentamidine, cytarabine, didanosine

Bacterial infection : legionella, leptospira mycoplasma, salmonella

Viral infection: mumps, coxsackie, cytomegalovirus, herpes infections

Parasitic infection: ascaris, cryptosporidium, toxoplasma

Autoimmune diseases: systemic lupus erythematosus, Sjogren's syndrome

Idiopathic

Table 52.2 Ranson's Criteria for Severity Scoring for Non-Gallstone Acute Pancreatitis.

At presentation	During the initial 48 h
Age > 55 years	Hematocrit fall > 10%
White blood cell count > 16,000	Blood urea nitrogen > 5 mg/dl
Blood glucose > 200	Serum calcium < 8 mg/dl
Serum alanine transferase > 250 U/dl	Arterial PO_2 < 60
Serum lactate dehydrogenase > 350 IU	Base deficit > 4 meq/l
	Estimated fluid sequestration > 6 L

Modified from Reference 19.

prominent symptom, following the onset after the abdominal pain. Depending on the etiology as noted in the previous section, the patient may have had a history of recent alcohol ingestion, fatty food intolerance, or recent surgery or trauma. Typically any patient with severe disease will present within 24 h of their symptom development as long as they have access to medical care. Because the range of severity is so variable, the objective clinical signs can also vary substantially from a virtually normal examination except mild upper abdominal tenderness to a patient with severe signs of systemic inflammation, shock, and respiratory embarrassment. While one should look for the presence of a Grey-Turner (flank) or Cullen (periumbilical) sign; this is not likely to be present in the early stages of AP, and is a rather nonspecific sign of retroperitoneal hemorrhage.(11) Jaundice may be presenting in patients with gallstones that are related to the cause of pancreatitis. Laboratory examination should include a complete blood count, serum electrolytes, and liver function tests. Most patients will have an elevated amylase value. However, as many as 0–20% of patients with AP will have a normal amylase value at presentation. A normal amylase maybe seen in patients with acute on chronic pancreatitis, or in the setting of hypertriglyceridemia. (12, 13) In addition, if the patient presents with an unclear time of onset (typically to the emergency room) a serum amylase and lipase should both be performed, because the amylase value may not be elevated if there has been an extended period of time before presentation. While it is commonly held that a serum lipase is more sensitive than a serum amylase, there is no improved accuracy for establishing the diagnosis of AP when both values are obtained, especially once the patient has been hospitalized during the entire time.(14) The only reason to have both values done is because the time course of the elevation of amylase differs from that of lipase. Serum lipase rises within 4–8 h of an episode of AP, peaks at 24 h, and returns to normal after 8–14 days.(2, 10)

Liver function tests should also be measured because an elevation of the hepatic transaminases may be a sign of biliary disease, and certainly if the alkaline phosphatase and bilirubin are significantly elevated, one must be concerned about the possibility of an impacted bile duct stone that may need urgent extraction if the AP is severe and also causing acute cholangitis. Because the pancreas produces many enzymes, several additional laboratory values have been measured in the serum or urine but these have generally been considered to be unhelpful at the current time. (15–18)

The case presented had serum values of amylase at 105 (normal 80) and lipase 250 (normal 60). This suggests two things: (1) that the patient is presenting at a later time in their disease course, because lipase is greater than the amylase (assuming 80 is the upper limit of normal); and (2) that the pancreas may be "burning out" because neither laboratory value is exceptionally elevated.

Scoring and Severity of Illness in Acute Pancreatitis

One of the most widely used scoring systems used for prediction of outcome from pancreatitis uses criteria originally proposed by Ranson (Table 52.2).(19) By the longitudinal collection of data at both presentation and later at 48 h, the provider immediately has an understanding that the disease is in evolution, has ongoing volume needs, and that serial observations are needed to predict what will happen. Around the world, alternative scoring systems based on clinical variables have been proposed such as that by Imrie (the Glasgow score) (20), or standard ICU-based scoring systems such as the Acute Physiology and Chronic Health Evaluation (APACHE II), or organ failure scores (21–23) (Table 52.3). None of these scoring systems remind us enough of the potential for an initially well-appearing patient to have a marked deterioration in the next 48 h. In general, patients with an initial Ranson's score ≥ 3 should be observed in either a high dependency or ICU.(24–27) In addition, an APACHE II score of > 8 would suggest that patients should be monitored (23, 25) (Table 52.3). Some experts have suggested that a CT scoring system is a more useful measure of final prognosis.(28) Balthazar

Table 52.3 Evidence Table for the Diagnosis and Management of Patients with Acute Severe Pancreatitis*.

Recommendation	Level of Evidence
Severity of illness of patients with severe acute pancreatitis should be quantified by an acceptable method, Ranson, APACHE, or Imrie.	Level 1C
Patients with severe acute pancreatitis as determined by scoring systems should be admitted to a high dependency or ICU for monitoring and therapy.	Level 1C
Presence of local complications involving the pancreas and surrounding tissues can be determined beyond 72 h by thin-cut CT scans with IV contrast.	Level 1C
Patients with SAP may be fed via the enteral route preferentially.	Level 1B
Elevated levels of C-reactive protein and/or procalcitonin on consecutive days may identify patients at risk for severe disease or at risk of complications.	Level 2B
Any patient with a possibility of gallstones as an etiology for AP should have an US performed to look for gallstones.	Level 1A
The presence of infection in a pancreatic pseudocyst or in pancreatic necrosis can be safely identified by FNA.	Level 1C
Patients with suspected pancreatic infection based on clinical signs such as fever, elevated WBC count, and organ failure with local signs of severe disease on CT scan should be considered for FNA to search for infection.	Level 2C
Patients with mild AP do not benefit from urgent ERCP	Level 1B
Patients with severe AP do not clearly benefit from early ERCP.	Level 1B
Prophylactic antibiotics should NOT be used in patients with SAP.	Level 1B
Patients with sterile necrosis do not benefit from routine debridement.	Level 1B
Patients with established pancreatic infection benefit from drainage and/or debridement, but there is no single best method of achieving this goal.	Level 1C

*See text for details.

Table 52.4 Balthazar's Computerized Tomography Severity Index Scoring System.

Inflammatory Process	Grade	Score	Subtotals
Normal	A	0	
Focal or diffuse enlargement Contour irregularity Inhomogeneous attenuation	B	1	
B + peripancreatic haziness/mottled densities	C	2	
B,C + ONE ill-defined peripancreatic fluid collection	D	3	
B,C + TWO ill-defined fluid collections or gas	E	4	
Necrosis			
None		0	
< 30%		2	
50%		4	
> 50%		6	
Total			

Modified from Reference 30.

Table 52.5 Components of the Extra-Pancreatic Inflammation on CT Score.

Sign of Extra-Pancreatic Inflammation	Grade	Score	Subtotals
Pleural effusion	None	0	
	Unilateral	1	
	Bilateral	2	
Ascites in any location (perisplenic, perihepatic, interloop, or pelvis)	None	0	
	One location	1	
	More than one location	2	
Retroperitoenal inflammation	None	0	
	Unilateral	1	
	Bilateral	2	
Mesenteric inflammation	Absent	0	
	Present	1	
Total			

Modified from Reference 33.

proposed a scoring severity illness that is best suited to describe local complications that are related to the pancreas.(28–32) Local complications such as the appearance of the pancreas and the presence, number, and location of fluid and/or air collections in and around the pancreas on CT scan may also be associated with the likelihood of death from these complications.(29) Balthazar's initial work focused only on these factors but the degree of necrosis seen on a thin-cut CT scan has added initial predictive value by dividing the volumetric area of necrosis into: none, < 30%, 30–50%, or > 50%.(30) The highest total score possible in the Balthazar CT severity of illness (CTSI) system is 10 (Tables 52.3 and 52.4). More recently, DeWaele and colleagues proposed a new CT severity score by prospectively studying 40 patients with severe AP (Table 52.5).(33) The CT scan was obtained in the first 24 h, and the following factors were considered as an extrapancreatic inflammation on CT scan (EPIC) score: pleural effusion, ascites, and retroperitoneal and mesenteric inflammation. Scores ranged between 0 and 7. Patients with a score value of 0–3 had

a mortality of 0%; while those with a score of 7 had a mortality of 67%.(33) The general usefulness of this score when compared to the previously described and more widely utilized scoring systems is unknown.

Several biomarkers have been proposed by investigators as markers of severity of illness, or to suggest the possibility of infection.(5, 6, 15, 18, 34) Most commonly serum C-reactive protein (CRP) has been suggested as a marker associated with pancreatic necrosis, but there is a latency of 24–48 h before the values

increase, thus limiting its value as an initial predictive marker. (1, 10, 15, 16) Interleukin-6 has also shown to be elevated to a greater degree in severe disease, but there is also little predictive value to the initial value.(2, 18) In a recent multicenter prospective evaluation, Rau and colleagues measured both CRP and procalcitonin in patients who were expected to have severe AP. They found that a procalcitonin level of greater than or equal to 3.5 ng/ml on 2 consecutive days early on (before day 4) predicted patients with severe infection and organ dysfunction requiring operative intervention and those who died with a sensitivity and specificity of 93% and 88%, when compared with CRP of 40% and 100%, respectively (34) (Table 52.3). While there have been several additional markers proposed as valuable in following patients, they are of limited clinical value in predicting the outcome, identifying the infection, or in triaging patients for admission to an ICU.

In the patient presented, a precise Ranson score cannot be calculated because we do not have a serum glucose or lactate dehydrogenase value at presentation, or values obtained at 48 h. At presentation, his age was the only factor for which he would be awarded points; just missing a point for his WBC of 15 K. A more comprehensive reading of his CT scan showed a small bilateral pleural effusions, peripancreatic haziness suggesting edema, bilateral retroperitoneal inflammation without fluid collections, and mesenteric edema. In your review of the CT scan you note that he has IV contrast and an estimated 50% necrosis. These findings would classify the scan as a value of Balthazar Grade C, because there are no fluid collections (2 points), and 50% necrosis (4 points). His total score, total for the CTSI, would be 6 points. According to Balthazar, patients with a CTSI of 0–3 had a mortality rate of 3% and a morbidity of 8%, whereas for patients with a CTSI of 7–10, the morality rate was 17% and the morbidity rate was 92%. His EPIC score would be 2 points for the bilateral effusions, 0 for ascites, 2 for retroperitoneal inflammation, and 2 points for mesenteric inflammation, for a total of 6 points and an estimated 28% mortality.

Definition of Complications
In 1992, experts in pancreatitis came together to develop consensus on the terms to be used for pancreatitis and its complications. (35) At the time, the term *pancreatic phlegmon* was abandoned; *necrosis* and *infected necrosis* were defined. Extrapancreatic fluid collections that persist eventually become demarcated from surrounding structures and are known as pancreatic pseudocysts. These pseudocysts do not contain epithelium, but their walls have granulation and fibrous tissue. At the Atlanta meeting, the meaning of pancreatic abscess was clarified to mean a localized or walled off collection of infection; previously known as an infected pancreatic pseudocyst.(35)

While the Atlanta classification has helped to unite and clarify work done at individual institutions, experts have recognized the need for revision of these terms.(36) Organ failure is now recognized to be a critical factor in predicting outcome, especially when persistent for more than 48 h.(37) In a revision of terms that is underway in 2008, it is expected that gastrointestinal bleeding will be dropped as a type of organ failure, and the importance of continuing multisystem organ failure will be emphasized.(36)

Radiological Evaluation
Radiological evaluation of the patient with suspected or proven AP can be grouped into three general indications: (1) to aid in the diagnosis, (2) to assist in severity assessment, and (3) to identify complications.(38) As noted previously, most patients with AP can be identified on the basis on their clinical presentation and laboratory assessment. Patients with mild disease typically do not require any radiological assessment. However, a CT can be helpful in patients who are more ill, or those in whom the diagnosis of AP is not clear. Alternative diagnosis such as duodenal ulcer perforation (especially, posteriorly into the retroperitoenum), aortic anuerysmal disease, and mesenteric or colonic ischemia may be confused with severe AP in some patients. On CT imaging, the normal pancreas has distinct borders and defined texture.(28–30, 38) In AP as the inflammatory process proceeds the pancreas becomes enlarged with interstitial edema, the texture is lost and the borders become indistinct. Stranding in the retroperitoneum, mesentery, and fluid collections can occur in many areas of the abdomen as the intensity of the inflammatory process advances. The inflamed pancreas can become necrotic and this is well seen on contrast-enhanced CT scans by injecting contrast rapidly (3–5 cc/s).(38) The normal Hounsfeld attenuation of the pancreas is 40–50 HU which enhances to 120 HU with a normal vascular supply at 40–45 s after scanning.(38) This time frame is the optimal time for pancreas scanning in someone with a normal cardiac output.(38) This contrasts with the best time for abdominal imaging at 70 s, when the attenuation of pancreas is typically 110 HU. A necrotic pancreas has as an attenuation of only 30 HU with an accuracy of 87% in patients with some necrosis, and approaching 100% in patients with more than 50% necrosis (38) (Table 52.3). Magnetic resonance imaging (MRI) is also able to identify necrotic areas and fluid collections (39, 40), but it is still a cumbersome study to perform in critically ill patients. However, the quality of the study has markedly improved in the last decade.

Radiological assessment has a certain role in helping to define the etiology of AP.

The possibility of biliary pancreatitis should be considered in all patients presenting with AP, at least at the first presentation. (5, 6) If gallstones are considered a possibility, then an US should be performed (Table 52.3). In severely ill patients who are in the ICU, this examination can easily be done at the bedside. However, it is not uncommon for patients with severe AP to have significant abdominal distention and abdominal gas which interferes with an US examination. In addition to transabdominal US, endoscopic US (EUS) may be useful in determining when gallstones are present in the common bile duct.(41) This may be especially helpful when the patient is pregnant, or if the patient has metal in place that would prohibit MRI.

CT is often used liberally in the emergency department (ED) to examine virtually any patient with abdominal pain, as a means

to "establish" a diagnosis. However, its best use maybe in helping to establish the likelihood of local pancreatic complications. As noted in the previous section, a noncontrast CT scan will provide the examiner with significant information. However, the use of multislice and even three-dimensional CT scanning can substantially add to information if pancreatic necrosis is present. However, IV contrast is required for most information to be obtained from a CT scan. In the initial inflammatory period of presentation when intravascular volume may be depleted, the use of IV contrast may increase the possibility of renal insufficiency. In addition, there is some concern that early administration (before 72–96 h) of IV contrast may cause local injury to the pancreas via microvascular sludge formation and further necrosis.(42) While this was seen in one animal model, it has not been reproduced clinically. Further, the full extent of pancreatic necrosis may not be seen in the first 1–2 days and thus it is best to delay a contrast-enhanced CT scan until it is clear that the study is needed, and that the most information can be obtained (3–4 days). Because CT scans are not required in patients with mild AP, a recent audit emphasizing this fact demonstrated that establishing the expected institutional guideline for when not to obtain a CT scan in patients with mild pancreatitis, audit and feedback to surgical staff decreased CT scan utilization in patients with mild biliary pancreatitis 27.1–13.1%.(43)

The ability of MRI to define necrosis, fluid collections, and potential etiologies such as gallstones has markedly improved.(39, 44, 45) Breath-held three-dimensional (3D) gradient multiphase with gadolinium administration scans has markedly improved the use of MRI over previous T1-weighted spin echo studies to detect areas of ischemia of the pancreas. In addition, specialized T2 images have improved the detection of both biliary and pancreatic ducts by using fluid as a contrast method. Thus, magnetic resonance cholangiopancreatography (MRCP) can help assess the possibility of a biliary etiology of the pancreatitis by clearly identifying ductal pathology in a noninvasive manner.(39, 40, 41, 45, 46) The provider must be aware of not only the difficulty of moving a patient safely to an MRI scanner but that infusion of gadolinium to a patient with renal insufficiency has resulted in some cases of nephrogenic systemic fibrosis, a rapidly advancing fibrotic process of the skin, which can be fatal.

Aspiration of Peripancreatic Fluid

Identification of Infection in and Around the Pancreas

Two factors appear to be of great importance in determining the risk for the development of peripancreatic infection: the presence and extent of pancreatic necrosis and the time from the initial presentation.(37, 38, 47, 48) Early (0–7 days) in the presentation of patients with severe AP, patients may manifest fever and leuckocytosis, and show signs that appear to indicate infection. However, these signs and symptoms are also consistent with a severe inflammatory process, and infection is rarely present. One exception to this general premise is in patients who have acute cholangitis who develop severe AP from biliary disease who are likely to have concurrent infection. In the vast majority of patients, infection becomes more likely beyond the second week of disease, and appears to be most common in the period of time between 21–28 days.(48–51) The development of an infectious complication related to the pancreas or surrounding fluid is directly proportional to the amount of pancreatic necrosis, with patients who have > 50% necrosis having an incidence of pancreatic infection of almost 50%.(50)

How Does Pancreatic Infection Occur?

While the exact mechanism of pancreatic infection is unknown, gut barrier failure with ensuing endotoxemia has been proposed as a major contributor to local infection and multiorgan failure in patients with severe AP.(52–55) Increases in gut permeability have been identified within 72 h of AP, and they correlate strongly with clinical outcome; that is to say, those with higher intestinal permeability develop multisystem organ failure and subsequent infection, with both organ failure (> two organs) and infection associated with a higher mortality.

The development of pancreatic infection is believed to most commonly occur from translocation of gram-negative and other common gut organisms.(52–55) Thus, prior to the period where antibiotic prophylaxis was commonly employed, *Escherichia coli*, *Enterococcus* sp., and *Klebsiella* sp. were most commonly isolated from infections.(56, 57) However, in the more recent time period *Staphylococcus aureus*, *Pseudomonas* sp., and fungal pathogens have been dominant isolates.(2, 37, 47, 48, 58–61) Many of these pathogens have broad resistance to antimicrobials, and thus identifying them is one of the major problems with antibiotic prophylaxis in severe AP.

The need to aspirate peripancreatic fluid to establish a diagnosis of infection is controversial (62, 63) (Table 52.3). The controversy stems from how information obtained from a fine needle aspiration (FNA) of peripancreastic fluid or pancreas would help influence management decisions. Infected pancreatic necrosis or a pancreatic abscess is best managed with debridement or drainage, while sterile necrosis is not managed with an operative approach.(64–67) Thus, it would seem logical that identification of infected fluid at an early time would be beneficial to the patient, particularly if a decision to delay treatment because infection is not identified causes continued or worsening organ failure.(63) Aside from the presence of gas in peripancreatic fluid on the CT scan, there is no certain way to ascertain whether peripancreatic fluid or sterile necrosis is actually infected except by direct cultures obtained percutaneously or from the operating room. Some authors believe that the patient groups with and without infection can be separated by clinical criteria alone as patients with infection are worsening at 3–4 weeks, while patients with sterile necrosis are not.(64) This idea is not universally accepted.(63) Some authors suggest that even if infection is identified, that it may be best to start antibiotics and allow the pancreas to coalesce so that areas of required necrosis are more safely identified and removed at a later time period.(64, 68, 69) Therein lies the controversy between those that believe antibiotics should be started liberally and that infection can be determined clinically at 3–4 weeks from onset, versus those who would not be willing to use antibiotics, nor operate on sterile necrosis, unless a FNA was performed and used to make decisions about antibiotics and intervention.(66–70)

FNA of peripancreatic fluid or necrosis is a safe procedure with a low complication rate (71, 72) (Table 52.3). Moreover, it

is able to accurately distinguish sterile from infected necrosis in a reliable manner.(71) FNA should be considered in any patient with clinical signs of sepsis and necrosis on CT, especially when they have been ill for more than 2 weeks. Aspiration can be performed either by CT or US guidance. In a classic study by Rau and colleagues (71), FNA guided by US was performed 193 times in 98 patients. Twenty-nine of 33 patients with infected necrosis were identified correctly by FNA a median of 13 days after admission. On the other hand, 55 of 61 patients with sterile necrosis were also correctly identified. There were six false-positive and 4 false-negative aspirates, all of which occurred in the first week of disease. The overall sensitivity of this method for identifying infection was 88% and a specificity of 90%. Importantly, no major complications were observed. In one of the largest reported series of CT-guided FNA of suspected pancreatic infection (72), of the 104 patients suspected of infection, 51 were identified with infection, all of whom had a positive culture.(72) Pancreatic infection occurred in the first 2 weeks in one-half of the patients. No complications were seen in this series. Thus, if one uses the FNA as one of the final factors in deciding on an interventional course, both US and CT guided FNA's are safe and reliable and informative, especially when performed after the first week of disease (Table 52.3).

> The patient presented earlier failed to improve and began to show clinical signs of worsening more than 2 weeks after his presentation. He had signs of organ failure continuing, and his original CT scan 4 days after presentation showed 50% necrosis, suggesting he would be a significant risk for morbidity and mortality, most likely from the development of pancreatic infection. A repeat CT scan at 21 days showed persistent fluid collections, and a percutaneous FNA was performed using CT guidance. The gram stain of the aspirate demonstrated gram-negative rods. The patient was placed on a carbapenem antibiotic and an interventional procedure was performed.

MANAGEMENT OF ACUTE PANCREATITIS

General Principles
The management of a patient with AP should be guided by an estimate of the severity of illness and in part the etiology of the disease.(5, 6, 24–27) As noted previously, the majority of patients will have a self-limited disease and require mild hydration and pain relief. Patients with signs of potentially severe disease, those that are obese, frail, or elderly should be monitored in a high-intensity nursing unit or ICU (Table 52.3). They require frequent assessment of vital signs, respiratory function, hemodynamics, and fluid balance. Pain relief can be provided by either systemic narcotics or via epidural catheter.(73, 74) Oxygen support via face mask is frequently required for hypoxemia, but the development of acute lung injury (75) or adult respiratory distress syndrome is one of the most common organ

system failures that occur during the first week, and it may only take a few hours to be manifested. Abdominal distention from ileus and fluid sequestration frequently leads to elevation of the diaphragms and when combined with pleural effusions both can work to decrease the functional residual capacity of the lung and predispose to respiratory failure and the need for intubation. During this initial phase, fluid sequestration is expected due to capillary leak from the inflammatory mediators.(76–79) While still somewhat controversial, a patient who is developing or failing to resolve signs of hemoconcentration is showing evolution of severe disease.(80) IV fluid support must be adjusted accordingly and may exceed 250–500 cc/h. Acute renal failure is seen in as many as 25% of patients and is associated with mortality.

Should Antibiotic Prophylaxis Be Used in Severe Acute Pancreatitis?
The mortality of patients with AP is seen in patients with severe disease, and in those who have multiple organ failure.(37, 50, 68) The presence of multiorgan dysfunction has been linked to the amount of necrosis in the pancreatic bed, which is also linked to the likelihood of pancreatic infection.(29, 30, 50) Since pancreatic infection is a known complication and in general a high-risk patient population can be identified, it is reasonable to ask whether or not targeted antibiotic prophylaxis should be used. (81) While there have been several studies and case series published (82–100), this question remains somewhat controversial in the eyes of many surgeons who have become accustomed to using carbepenem or fluroquinolone prophylaxis over the decade of the 1990s.(96) However, the two most recent trials, both randomized placebo controlled trials of antibiotic prophylaxis for acute pancreatitis do not support the use of prophylactic antibiotics (84, 85) (Table 52.3). The combination of these trials had 214 patients with severe AP, of whom 38 patients (17.8%) who received antibiotics developed infected necrosis, and 31 patients (14.4%) without prophylaxis did not.(84, 85) Similarly, the need for surgery or hospital mortality was not different between the groups. While antibiotic prophylaxis is no longer recommended (Table 52.3) (5, 6), certainly patients who develop nosocomial infection should be appropriately treated with antibiotics.

How Should Patients with Severe Acute Pancreatitis Be Fed?
Patients with a mild course of AP will typically be able to resume oral intake within 5–7 days, perhaps even earlier. A decade or more ago, most providers were taught that patients with severe AP should be alimented with parenteral nutrition, and enteral nutrition would not be considered.(100–104) Today we understand that parenteral nutrition is associated with gut mucosal atrophy which may worsen the translocation of bacteria from the gut already likely in this disease state, and therefore may increase the possibility of infection.(105) While the data from clinical trials or case series in this area are fairly weak, there are indications that it is certainly possible to feed the gut in patients with AP and that adequate calories can be delivered (Table 52.3).(105–117)

The trials do not support that enteral feeding provides a mortality advantage.(106, 114, 117) However there are also some interesting data examining the inflammatory process as measured by cytokines which suggest that enteral feeding lowers the inflammatory response coming from the gut.(115) Because the clinical trials have been small, meta-analysis has been performed. The Cochrane meta-analysis suggests that nasojejunal feeding be started as soon as is feasible.(111) Some patients may not tolerate adequate calories via the enteral route and either a combined enteral/parenteral period of support should be offered or a brief period of parenteral nutrition may be needed if patients are severely malnourished at presentation.(114) Glucose control may be difficult, and based on current evidence, some effort should be made to keep the glucose less than 140 mg/dl, if not less than 110 mg/dl.(118)

Should Urgent Endoscopic Retrograde Pancreatocholangiography Be Performed in Patients with or Without Pancreatitis?

Patients with biliary pancreatitis and mild AP do not benefit from early ERCP(Table 52.3).(6) In this group, ERCP, endoscopic spincterotomy, and stone removal are utilized once clinical signs of AP have abated.(6, 119) The major debate over ERCP (with or without spincterotomy) has been whether or not ERCP should be used in patients with severe AP, with or without biliary obstruction.(120–127) There have been seven randomized controlled trials of this question, but two of these have been published in abstract form only. A recent meta-analysis considered only the five fully published studies with 717 patients stratified according to the severity of the AP.(128) They concluded that ERCP should not be performed urgently in patients with AP (Table 52.3).. (128) While the point estimate for reducing local complications in this analysis was less than 1, the confidence interval (CI) was quite wide and exceeded 1.0. This analysis demonstrated that ERCP was successful around 92% of the time, and stones were present 39–46% of the time. There was a 2.9% complication and a 0.8% mortality rate presumed to be directly attributable to the ERCP in both groups. Given the finding that less than half of patients have stones identified and that there is a significant complication rate, it is reasonable to perform an endoscopic ultrasound (EUS) examination to identify the presence of stones before undertaking an urgent ERCP. The earlier Cochrane analysis that included 511 patients from three trials concluded no beneficial or harmful effect of ERCP on mortality, but a decrease in pancreatic complications was seen with early ERCP (odd ratio [OR] = 0.27, 95% CI = 0.14–0.53).(129) However, the complications that were included in this and another more recent meta-analysis were widely variable.(129, 130) The Moretti meta-analysis utilized five studies and concluded that there was no impact on mortality with early ERCP, but there was benefit with a number needed to treat of three in those with severe pancreatitis.(130) On the basis of the quality of the data, the lack of effect on mortality, and a question if there is any benefit to ERCP in patients with possibilities and a review of the risks and benefits, early ERCP cannot be routinely recommended.

The patient presented here was recognized as having severe AP due to progressive hypoxemia in the ED while being evaluated. He required organ system support with mechanical ventilation and ongoing hydration. Enteral feedings were begun on hospital day 3 via a nasojejunal tube, and antibiotics were not utilized. An US did not demonstrate gallstones, and ERCP was not performed.

Interventional Management

Early Period Interventions

During the early period of this disease, the primary management issues are in intensive support of the patient with severe AP who is likely to have one or more failing organs. While it was proposed that early debridement of necrotic pancreatic tissue would improve the clinical outcome of patients with severe disease, this practice was largely abandoned in the United States after patients who had early necrosectomy (before 14 days) had a 58% mortality versus those with late debridement who had a 27% mortality (Table 52.3).(131) The trend toward delay in surgery has further intensified since this publication in that most surgeons would delay surgical or alternative interventions until 3–4 weeks had passed.(88, 132–134) The rationale behind this general approach is theoretically that the disease of the pancreas has more clearly demarcated, and the separation between viable and nonviable as well as infected and noninfected tissue is more clearly defined.(2, 10) In addition, the patient should have improved resuscitation, and hopefully less organ failure. Early intervention should be reserved for patients with proven infected necrosis, or those with alternative complications such as acute cholangitis necessitating ERCP, ischemic or perforated bowel, or bleeding.(135, 136)

One important and increasingly recognized complication seen in patients with a profound inflammatory process of the abdomen and a massive resuscitation is that of intra-abdominal hypertension (IAH) and abdominal compartment syndrome (ACS).(137–140) Most experts would agree that ACS is defined as measured pressures in the abdomen in excess of 25 mmHg. In a recently reported series from England, of the 18 patients with severe AP, 11 patients developed IAH (pressure > 15 mmHg, median = 20 mmHg), with 10 developing ACS.(138) Patients in this series with IAH had higher scores of organ failure, stayed longer in the ICU, and had a significantly higher mortality than those who did not developed increased intra-abdominal pressure. Laparostomy and drainage decreased intra-abdominal pressure by a median of 11 mmHg and relieved the elevated pressure in all patients. These same authors described CT findings of IAH and ACS in patients with severe pancreatitis.(141) The CT findings consistent with IAH/ICS include narrowing of the intrahepatic inferior vena cava (< 3 mm), round belly sign (increased ratio of anteroposterior to transverse diameter measured where the left renal vein crosses the aorta, [subcutaneous fat not included, value > 0.8]), direct renal compression or displacement, bowel wall thickening (> 3 mm) with contrast enhancement, compression or displacement of solid abdominal viscera, bilateral inguinal herniation, and an elevated diaphragm (above the 10th thoracic vertebrae).

The round belly sign and bowel wall enhancement signs were more commonly seen in patients with IAH than those without, and bowel wall enhancement was seen significantly more commonly in patients with ACS. Given these and additional reports, IAH and ACS should be considered as possible factors influencing organ dysfunction in patients with severe AP (SAP). Whether elevations of intra-abdominal pressure when in association with organ failure in SAP should always be treated with laparostomy is also controversial (142), and alternative, preventative, and therapeutic measures such as a traditional Chinese colonic and catheter drainage have been proposed.(143–145)

Sterile Necrosis
The nonoperative management of sterile necrosis for an extended period of time is now well established with a low mortality of 0–10% (Table 52.3).(2, 6, 10, 68, 136, 146) In addition, operative intervention of sterile necrosis can lead to superinfection and conversion to infected necrosis . There are no clinical trials in this area, and most institutions have developed internal management algorithms. In one case series, patients with sterile necrosis who were managed with debridement had a higher mortality (39%) versus those who were managed nonoperatively (15%).(6) Moreover, a large case series demonstrated that 56 of 57 patients with sterile necrosis could be managed nonoperatively with a low mortality (3.5%).(68) Meta-analysis of the trials is not possible because they were not randomized. However, the surgical treatment of pancreatic necrosis appears to have a higher mortality rate (11.9%, 95% CI = 5.3–22.2) than conservative treatment (2.3%, 95% CI = 0.3–8.2) in patients with sterile necrosis (Table 52.3). (6) Whether there is any role of debridement of sterile necrosis at any time is a matter of debate.(63, 64) If after a prolonged period of observation (perhaps as long as 6–8 weeks), if the patient with extensive necrosis has not improved or is unable to tolerate feeding, operative debridement may be considered.(68)

> The patient presented here continued to be managed in the ICU with ongoing organ support for 3 weeks while he was identified as having sterile necrosis. At day 21 however, a FNA was performed that demonstrated gram-negative rods, and thus the patient was diagnosed with infected pancreatic necrosis, and an intervention was planned.

Indications for "Operative" Intervention
No clinical trials can help to answer the question about the absolute indications for operative intervention in patients with SAP.(6) Almost all surgeons would agree that patients who have identified infected pancreatic necrosis (for example by FNA or gas on CT scan) should have drainage.(147–157) Nordback and colleagues presented data on 25 patients with proven infection, organ failure, or recurrent serum markers of infection.(68) They began antibiotics in this group of patients. Three of these 25 patients improved without surgery, and five patients died in spite of surgery. Thus some experts believe that there may be a highly

selected group of patients who can be treated without drainage, but that this approach must be done with great caution.

The timing and approach to achieving drainage of pancreatic infection would also be a matter of debate and would be greatly influenced by the personal experience of the surgeon, the team caring for the patient, and the institutional expertise and bias in managing these difficult problems.(147–153)

Some surgeons would consider laparostomy for a patient without proven infection in the setting of multisystem organ failure and further deterioration (sterile necrosis) (63), but patients in this group have an exceedingly high mortality, and there does not appear to be incremental benefit from operative intervention.(136) Nonetheless, it is difficult to have a patient with these problems die without a laparotomy. As noted previously, patients with a protracted course (6–8 weeks), sterile necrosis and persistent organ failure may be considered as candidates for intervention. Finally patients with other surgical complications of AP such as bleeding and bowel ischemia certainly would prompt intervention.

Goals of Therapy in Infected Pancreatic Necrosis
The intent of any intervention in a patient with known infected pancreatic infection is to remove the infected necrotic pancreas without removing viable pancreatic tissue or injuring other organs.(10, 136) At the same time, removing the full extent of the infection is the primary goal. Because the distinction and definition between viable and nonviable and infected and noninfected material is difficult, the method selected must allow for continued evacuation of infected debris and exudates. All techniques must consider hemostasis.

Method of Pancreatic Drainage
Case series from single institutions dominate the literature about the preferred approach to drainage of pancreatic infection ((Table 52.3).(147–153) Each institution appears to have excellent recent results, thus the reader can only be guided by local experience (Table 52.3). One prospective trial examined formal pancreatic resection versus debridement of necrotic tissue with continuous peritoneal lavage in 21 total patients. (154) Formal pancreatic resection was associated with a higher mortality, and formal resection has now been abandoned in favor of a more limited necrosectomy.(154) In the remote past, a technique called closed marsupialization was described whereby both edges of the opened greater omentum were sutured, respectively, to the upper and lower peritoneal borders of the transverse abdominal incision, forming a marsupium separating the greater and lesser abdominal cavities from each other.(155, 156) The abdominal incision was then sutured to close the opening of the marsupium. Open packing is considered a form of marsupialization.(148)

In general, the open surgical approach to drainage includes necrosectomy followed by an open packing or closed drainage. If the open packing approach is used, it is employed until all infected and nonviable tissue is removed at serial debridement, often every 48 h.(148) At that point, the abdomen could be closed over drains as in the closed approach, or continued packing could

occur until closed.(150, 153) This approach was initially favored because of the substantial improvement in mortality when compared with historical controls from previous decades when the mortality of infection associated with pancreatitis was as high as 80%. As an alternative to the open packing approach, necrosectomy is performed followed by closed drainage.(136, 149, 153) This technique is very popular but the surgical team must be willing to reconsider the need for reoperation or repeat drainage if the patient is not improving.

The role of continuous lavage with these techniques is discussed below. Large prospective case series have described operative results from: (1) necrosectomy combined with open packing technique (147, 148, 152), (2) necrosectomy with planned staged laparotomies with repeated lavage (150), and (3) necrosectomy followed by closed continuous suction lavage of the retroperitoneum.(149) While the techniques have not been directly compared, open packing has been associated with a higher morbidity rate due to higher incidences of intestinal fistulae (50% vs. 15.6%), bleeding (17% vs. 5.7%) and ultimately incisional hernias (32%).(6)

Surgical Approach

When an open approach to drainage is selected, the first decision is to what incision should be selected. Some authors prefer a subcostal incision (63), while others prefer a midline approach. A bilateral subcostal incision provides excellent exposure but compromises spontaneous respiratory breathing and probably contributes to the need for prolonged ventilation and its subsequent risks. Thus, a midline incision is preferred. The lesser sac is accessed in standard fashion to perform the bulk of the necrosectomy. However, the surgeon should carefully examine additional areas known to be inflamed or involved on previous CT scans, especially the gutters and pararenal space. The base of the mesentery should also be carefully examined. A cholecystectomy should be performed when biliary pancreatitis has been the etiology of AP.(6) Many surgeons would place a jejunostomy for enteral feeding at this initial procedure.(6)

After irrigation and removal of all infected and necrotic tissues, large bore drains are placed and can be used if the abdomen is closed over these drains, or if an open packing technique has been selected. The role of continuous irrigation has not been investigated in a trial. However, it has been used extensively by groups in Europe with excellent results.(149) Berger described the use of continuous irrigation through lesser sac drains to keep the area free of accumulated debris and infection, and to minimize the potential need for further debridement of vital tissue.(149) The irrigation solution utilized was a slightly hypertonic, potassium-free solution normally used for continuous peritoneal lavage at a median rate of 8 l/24 h for an median time of 25 days. In most patients (70%) in addition to lesser sac lavage, his group placed two additional catheters (Tenckoff) for postoperative intraperitoneal lavage. The lavage fluid studies revealed high levels of immunoreactive trypsin, phospholipsase A2, and endotoxin early postoperatively. The overall mortality in this high-risk patient population was 8.2%. These are obviously excellent results using this technique.(149) Some U.S. surgeons prefer the use of intermittent irrigation and suggest that this is adequate to achieve the

same endpoints because surgery is delayed until demarcation of necrotic tissue has occurred.(166)

If the abdomen has been closed over drains, the team must be open to the idea that additional fluid, necrotic debris, and/or infection may accumulate, and that additional drainage procedures may be required.(68, 153, 158, 159) These may be performed percutaneously, or additional open or endoscopic procedures may be required. The need for these additional procedures are more common than not. In collected series from the period 1998–2006, patients managed with open surgical debridement with local bursa lavage includes more than 700 reported patients, 43% of patient complications, a reoperation rate of almost 30%, and a hospital mortality of 14.7%.(10)

Minimally Invasive Techniques

The use of percutaneous, laparoscopic, and endoscopic less-invasive techniques for the management of infected pancreatic necrosis have been increasingly described in the literature. (162–165) Each of these approaches is intended to minimize the additional surgical insult from debridement and its attendant inflammatory process. The number of cases reported with any of these approaches is still somewhat small and the results are limited. Some questions remain about whether the patients selected for this treatment are fundamentally different and less ill than patients who have had open therapy.(170) Increasingly the retroperitoneal approach is accessed via the left flank with good results. In 2004, a Dutch group designed the PANTER-study which is prospective randomized controlled trial that is designed to enter 88 patients into one of two arms: (1) a minimally invasive group with drainage followed by videoscopic retroperitoneal debridement, or (2) maximal necrosectomy by laparotomy with both groups receiving continuous lavage.(174) The results of this important study are expected later in 2008 and should help us understand if one of the approaches is preferred.(174)

> The patient underwent open debridement of the lesser sac and peripancreatic necrosis is seen in the left flank and at the mesenteric root, with tissue sent for microbiology (bacteria and fungus) and to pathology. The necrotic areas were reasonably well demarcated and little bleeding occurred. A cholecystectomy was not performed because the patient did not have gallstones, and a feeding jejunostomy was placed in the proximal jejunum. Four large bore drains were placed into the lesser sac for continuous lavage and drainage, with two additional drains placed in the left gutter. The abdomen was closed and a follow-up CT scan was performed 10 days later which showed another collection located in the right pararenal space. Percutaneous FNA showed gram-negative rods, and a percuatenous drain was placed. After 20 additional days of ICU and hospital care the patient was discharged to a rehabilitation hospital to gain physical strength. He has his two lesser sac drains still in place, but the irrigation had stopped after 2 weeks.

SPECIAL PROBLEMS

Gastrointestinal Bleeding and Hemorrhage in Acute Pancreatitis

Bleeding complications can occur from intraluminal or ductal hemorrhage or from pancreatitis-related vascular lesions such as pseudoaneurysms of the vessels in the retroperitoneum involved in the inflammatory process.(175–184) Necrosis, inflammation and infection each can cause erosion of a major vessel with massive bleeding into a pseudocyst, into a drain, into the lumen of the GI tract or freely into the peritoneal cavity. The frequency of fatal hemorrhage in patients with AP varies 1.2–14.5% and includes hemorrhage both into the pancreatic bed and into the GI tract. (176–178) In one study of 449 patients with AP, Sharma and colleagues identified bleeding in 28 (6.2%) (180), 16 with GI hemorrhage and 12 with hemorrhage into the pancreatic bed. Risk factors for bleeding included pancreatic necrosis, sepsis, fluid collections, and organ failure. Pseudoaneurysms were seen in five patients, four of whom were treated successfully with embolization. In a patient with suspected bleeding, the first step is to determine if bleeding is within the GI tract or within the pancreatic bed by the combination of endoscopy and either US or CT scan. Typically arteriography would be performed if intra-abdominal bleeding is suspected with coiling of bleeding vessels as identified. (175–178) This approach requires expert interventional radiologists, and can avoid difficult and often ineffective open operative approaches.

Pancreatic Abscess

A pancreatic abscess was formally known as an infected pancreatic pseudocyst and develops following an episode of AP. Several approaches to this problem have resulted in low morbidity and high survival rates. Probably the most commonly utilized approach to a pancreatic abscess is percutaneous drainage.(160, 161) Thus a skilled practioner should be able to safely access the pancreas via one of a number of routes.(57) The catheter ideally will have multiple side holes and a minimum diameter of 12–14 F. Typically these catheters are placed via a Seldinger technique and can be added or "up-sized" as needed. The size of collections should be monitored by US or CT as they collapse around the catheter. Several catheters may be required. Patency of the catheters should be enhanced by routine flushing of the catheters. A careful record of the amount of drainage should be maintained as a connection with the main pancreatic duct, or one of its branches may result in prolonged pancreatic drainage.

Pancreatic Pseudocysts

Fluid collections outside the pancreas are extremely common both in the early and later stages of AP. In a series of 160 patients with AP, a pancreatic pseudocyst developed in seven patients (4.2%) with one infection, and hemorrhage in four patients.(6) Most of these complications are not manifested until 3–4 weeks after clinical presentation, and are seen in those with the most acute forms of the disease. If the acute fluid does not resolve, then a pseudocyst may develop over the next weeks; typically 4 weeks are required for a pseudocyst wall to form.(38) An estimated 10–15% of patients with AP will develop a pseudocyst, while

those with chronic pancreatitis will develop pseudocysts more commonly.(185–188)

Acute pseudocysts are friable with a thin capsule and they can rapidly change size, diminish in growth, rupture into surrounding structures, or resolve spontaneously.(38) Fluid collections within the pancreas that have a wall and low attention consistent with necrosis are now referred to as *well-defined organized necrosis.* Spontaneous resolution has been reported in 40% of the acute pseudocysts and known to be present for less than 6 weeks, but they tend to be more stable of present for more than 12 weeks. (185–188) Complications of pseudocysts such as rupture, hemorrhage, or infection merit treatment but the identification of those at greatest risk can be problematic. A CT Scan done in 75 patients with acute pseudocysts reported that half of patients resolved or remained asymptomatic, while the other half needed intervention.(172) The size of the pseudocyst does not by itself predict which of the pseudocysts will resolve and thus, in general, these do not require intervention unless they are clearly symptomatic . The previous "rule" of intervening when the pseudocyst is greater than 6 cm and has been present for more than 6 weeks is no longer considered to be standard.(188)

If intervention is required to treat a pseudocyst, a variety of acceptable approaches can be utilized depending on the clinical presentation and indication for drainage. The pancreatic ductal anatomy if known may indicate a preference for endoscopic, or possibly a direct surgical approach.(187) Endoscopic and open surgical approaches each have reported good success rate with no strong preference for one approach. Percutaneous approaches may have a higher recurrence rate, while open surgical approaches may have the lowest rate.(188)

Outcome

As is true with most critical illnesses of long duration, the importance of quality of life of surviving patients has now been reported. In patients with alcohol-related AP, the long-term outcome is confounded by the commonly present medicosocial problems seen with alcohol abuse. Recurrent pancreatitis, abdominal pain, diabetes, and polyneuropathy may be seen. Patients who have been managed with an open abdomen may have developed an intestinal fistula and its attendant long-term problems in management, or commonly they will have an abdominal hernia. Chronic pancreatic problems including pseudocysts, splenic vein thrombosis, and mesenteric pseudoaneurysms can occur, but will not be discussed in further detail.

The Short Form-36 (SF-36) assessment of health-related quality of life was reported on 145 patients with AP and was compared with age- and gender-matched controls. Of the 145 patients, 87% returned to work, 27% suffered recurrent attacks of pancreatitis, and 43% developed diabetes. Of the 113 patients with alcohol-induced pancreatitis, 30% were abstinent and 28% were problem drinkers, alcohol-dependent, or alcoholics.(189) Hochman and colleagues followed 42 patients 24–36 months after treatment of SAP.(190) In another study of patients out 2–2.5 years after a severe attack of AP, patients continued to suffer physical complaints when compared with the population at large, and the degree of disability correlated with the initial severity of the AP. Pancreatic dysfunction was also very common with 76% of

patients experiencing one or more of the following symptoms: abdominal pain, diarrhea, unintentional weight loss, new onset diabetes mellitus, and the need for regular pancreatic enzyme supplementation. These data suggest that survivors of SAP should continue to have close follow-up years after recovery from a severe episode.(190) The SF-36 has also been reported on 32 patients with sequential debridement and SAP.(191) In this study, all patients had a SF-36 score of > 60% and 20 of the 32 patients had a score of 70–80, which would indicate a good quality of life. However, most patients had abdominal wall dysfunction, and five required reoperation for a symptomatic hernia. Twelve patients returned to their previous work within 6 months of discharge. (191) Thus while patients with SAP may have long-term sequelae of their disease, it is also possible to have a high quality of life after a prolonged course of treatment.

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53 Incarcerated femoral and inguinal hernias
Robert T Brautigam

A 20-year-old morbidly obese female, 3 months post-partum, presents with nausea, vomiting, and right groin discomfort. A focused physical examination does not demonstrate any palpable right groin mass, but there is vague tenderness at this location. Computerized tomography (CT) scan of the abdomen and pelvis with oral contrast reveals dilated loops of small bowel and a transition point in the right groin area. The patient is diagnosed as having an incarcerated right femoral hernia and proceeds to the operating room for a femoral hernia repair.

INTRODUCTION

Hernias in the groin may be classified as inguinal (direct and/or indirect) and femoral. The focus of this chapter will be to discuss the incidence, pathophysiology and surgical anatomy, clinical presentation, diagnostic workup, treatment, and special considerations of femoral hernias. Comparisons will be made between femoral and inguinal hernias.

INCIDENCE

What is the incidence of femoral compared to inguinal hernias?

Inguinal hernias (direct and indirect) are more common than femoral hernias. Of the inguinal hernias, indirect is the most common in men and women.(1) In an extensive review, Dr. Glassow at Shouldice Hospital in Toronto, Canada, documented over 75,000 herniorrhaphies performed at his institution from 1945 to 1970. Of these surgeries, 4,874 were to repair femoral hernias; thus when compared to femoral hernias, inguinal hernias were 30 times more common. Additional findings by Dr. Glassow identified three separate groups of patients with femoral hernias. The first group had primary femoral hernias, which occurred more commonly in men than women, at a ratio of 7:5. Men were found to have concomitant direct inguinal and femoral hernias about 50% of the time. The occurrence of a direct inguinal hernia was rare by itself in women, and the combination of a direct inguinal hernia and a femoral hernia in women was even rarer. A second group of patients with a femoral hernia had previously undergone an inguinal hernia repair. Of more than 100 cases, only 2 occurred in women. Factors associated with femoral hernia occurrence after a repair of an inguinal hernia are increased tension during the initial inguinal hernia repair, increased abdominal pressures, previous bilateral inguinal hernia, and older age. The third group of 400 patients had previously undergone femoral hernia repair at another institution and presented with recurrent femoral hernias. Details regarding the initial diagnosis and surgical repairs were not known.(2)

A follow-up retrospective study by Dr. Glassow at Shouldice Hospital reviewed 2,105 femoral hernia repairs from 1967 to 1983. In this study, factors associated with femoral hernias were male gender (3:1), age greater than 50 years, and body weight below average.(3) More recent evidence supports the widely held belief that when hernias occur in women, they are more likely to be femoral rather than inguinal hernias.(4) A review of the literature by McIntosh found that femoral hernias were more common in elderly patients who had previous inguinal herniorrhaphy and a higher incidence was noted in females (1:4). It is thought that the higher incidence of femoral hernias among females may be attributed to the larger, oval shaped femoral canal. This may also predispose the hernias to strangulation.(1) Although McIntosh identified that femoral hernias accounted for less than 10% of all groin hernias, they had a 40% incidence of presenting as incarcerated or strangulated.(5) This is compared to Gallegos et al. who found a 5% rate of strangulated inguinal hernias at the time of presentation to the hospital.(6)

PATHOPHYSIOLOGY AND SURGICAL ANATOMY

Why do femoral and inguinal hernias develop? Where do they present?

The pathophysiology of recurrent inguinal and incisional hernia formation is thought to be caused by disturbances in collagen metabolism by the tissue fibroblasts, specifically a decrease in type I to type III collagen ratio. Type I collagen provides tensile strength and type III is viewed as an "immature" collagen. Therefore, tissue is weaker when there is less type I collagen, which may contribute to hernia formation and reoccurrence.(7, 8) In addition to these pathophysiologic tissue changes, the femoral canal is larger in women, which may lead to the development of a femoral hernia. Amid, et al. provided a detailed description of the anatomy of the femoral canal and described the anatomic cause of femoral hernia formation. The femoral canal relies on three structures. One is the weaker transversalis fascia with its limited connective tissue. It joins a second stronger structure, the transversus abdominis aponeurosis, in the groin. It is stronger due to adequate collagen and provides strength. Lastly, the lacunar ligament, found medially, closes off the femoral canal in close proximity to the femoral vein. The femoral canal ends as a closed area below the inguinal ligament.(9) As abdominal pressure increases and tissue levels of type I collagen are low, the closed area of aponeurotic tissue separates and a femoral hernia develops.

Direct inguinal hernias occur due to the alteration in collagen content as noted above. The weakness in the transversalis fascia within Hesselbach's triangle associated with high intra-abdominal pressure leads to the development of direct hernias. Indirect hernias in men occur due to a patent process vaginalis, which usually obliterates by 2 years of age. Twenty percent of men
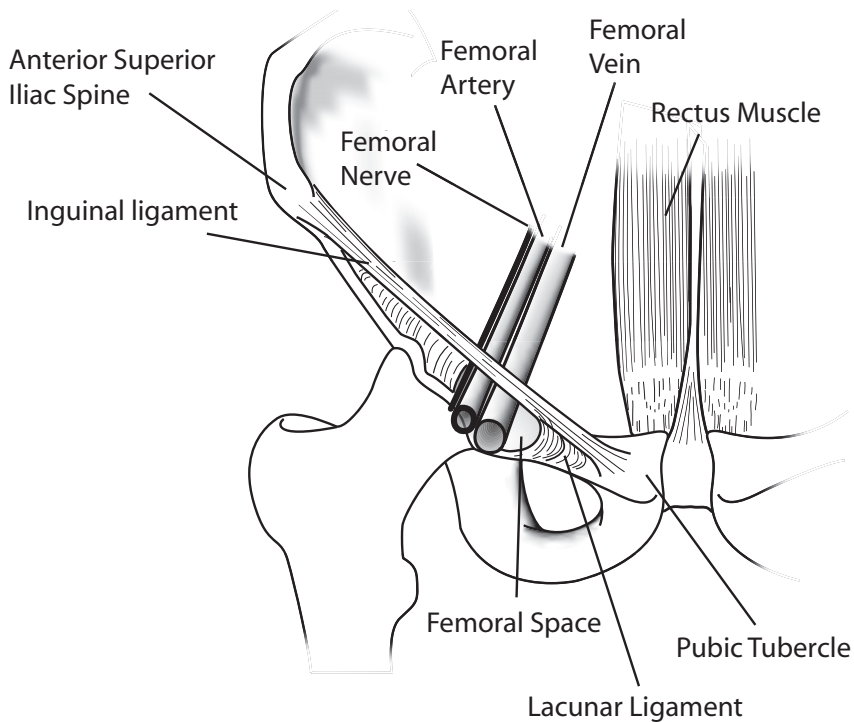
Figure 53.1 Right groin anatomy.

continue to have a patent process vaginalis; 5% will develop an indirect inguinal hernia during their lifetime.(1)

In contrast to direct and indirect inguinal hernias which develop above the inguinal ligament, femoral hernias develop below the inguinal ligament. The boundaries of the femoral canal include anteriorly, the inguinal ligament (also know as Poupart's ligament); posteriorly, the pectineal ligament (also known as Cooper's ligament); laterally, the femoral vein; and medially, the lacunar ligament (also known as Gimbernat's ligament).(10) The description of the femoral area in Figure 53.1 is limited to basic anatomy (Figure 53.1). Additional literature should be reviewed for extensive descriptions of the detailed anatomy of the inguinal area.(11–13)

CLINICAL PRESENTATION AND DIAGNOSIS

How do patients with direct and indirect inguinal hernias present when compared to patients with femoral hernias? How do we make these diagnoses?

Direct and indirect inguinal hernias usually present as a bulge or tenderness above the inguinal ligament. The direct inguinal hernia usually presents as a bulge palpated during examination of the inguinal area overlying Hesselbach's triangle which is behind the external inguinal ring. This bulge will be accentuated during a Valsalva maneuver. Indirect inguinal hernias are usually appreciated during palpation of the internal inguinal ring during a Valsalva maneuver in men but are difficult to detect in women. Typically inguinal hernias may be diagnosed by physical examination alone. However, the use of ultrasound and/or CT scan may be indicated to provide the diagnosis if the physical exam is inconclusive.

Because femoral hernias occur much less frequently than inguinal hernias and may be difficult to accurately diagnose on physical exam alone, other diagnostic modalities may be indicated. These additional studies will also guide the surgical approach and the type of repair. This is in contrast to inguinal hernias that are typically approached through an inguinal incision. The next section will review the literature related to diagnosing femoral hernias. Femoral hernias most commonly present as a swelling, bulge, or tenderness below the inguinal ligament (Figure 53.2). They occur more commonly on the right side since the sigmoid colon obstructs the femoral canal on the left side. However, an accurate clinical diagnosis may be difficult.(4)

A retrospective chart review study by Naude et al. from February 1990 to June 1995 identified 22 patients with a postoperative diagnosis of a femoral hernia. The operative findings were not consistent with the preoperative diagnosis of 13 inguinal and 5 femoral hernias, 3 groin abscesses and 1 incidental finding at the time of a vascular procedure in the groin. It is important to note that 19 of the 22 patients had emergent repairs.(14) Hair et al. reviewed the records of 379 patients enrolled in a prospective clinical trial evaluating the operative management of groin hernias from January 1994 to January 1997. They sought to determine if the preoperative clinical diagnosis of a femoral hernia was confirmed at the time of surgery. All patients were electively referred to the hospital by general practitioners, and the hospital surgical staff examined all the patients. Both general practitioners and hospital surgical staff had difficulty differentiating inguinal and femoral hernias. General practitioners had a sensitivity of 27% compared to the hospital surgical staff who had a sensitivity of 50% for diagnosing femoral hernias. Thus, Hair
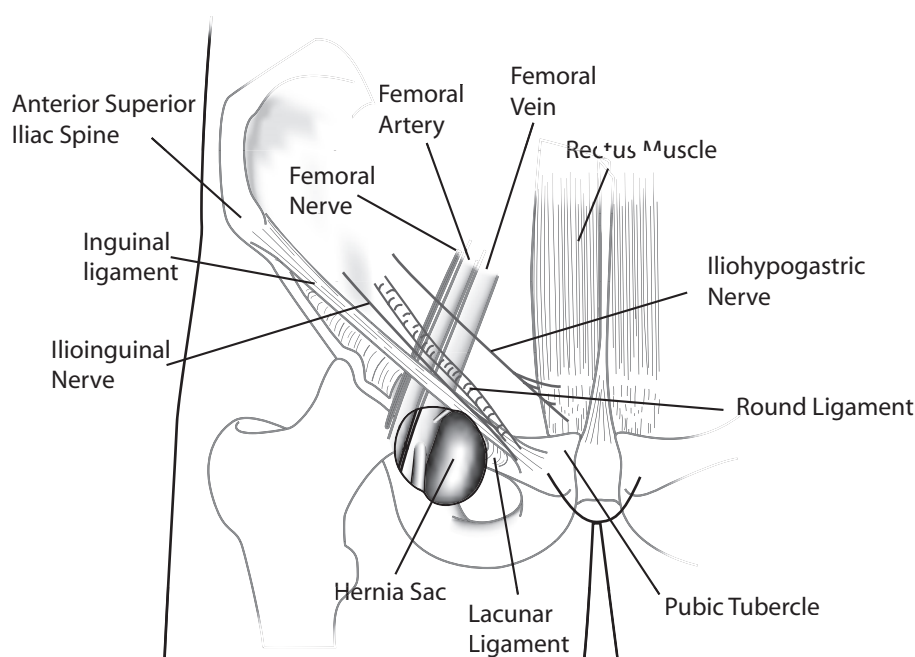
Figure 53.2 Right groin anatomy with femoral hernia.

et al. concluded that the diagnosis of femoral hernias by physical examination alone is problematic.(15)

Because of the difficulty of diagnosing a femoral hernia by physical examination, diagnostic imaging studies are needed to correctly identify the type of groin hernia, so as to direct the surgical approach. The least invasive and safer modalities of diagnostic testing should be used first if available. Ultrasonography is a dynamic evaluation of the groin, but it may be limited by patient's habitus and the ultrasonographer's experience. In a study by Lilly et al. 41 patients were evaluated for groin hernias with a history and physical examination followed by an ultrasound performed by surgeons and fellows. Sixty-five groin hernias were identified; 24 patients had bilateral hernias. Ultrasound was 92% accurate in identifying a hernia.(16) In another study, 52 patients with a history suggesting a groin hernia, but with a normal or inconclusive examination, were evaluated by ultrasound (104 groins evaluated) followed by a subsequent herniography. Ultrasound when compared to herniography had a sensitivity of 29% and a specificity of 90%. Thus, a groin hernia can most likely be excluded with ultrasound, but additional diagnostics studies should be completed if the ultrasound shows no abnormalities.(17)

A retrospective study by Sutcliffe et al. reviewed the outcomes of 112 patients evaluated by herniography to identify the presence of a hernia if the examination was normal or equivocal. They found a sensitivity of 96.6% and a specificity of 98.4% with no significant complications from the procedure.(18) Another retrospective study examined the safety and effectiveness of herniography in 64 patients. Herniography was completed if the patient had a suspected occult hernia. Twenty-three patients (36%) were identified with a hernia, with a sensitivity of 94% and a specificity of 95%. Three patients (5%) developed complications which may have occurred due to bowel injury at the time of contrast administration into the peritoneal cavity. These were localized peritonitis and urinary retention treated conservatively and generalized peritonitis treated with laparotomy that revealed generalized peritoneal erythema but no injury.(19) Because of the risk of complications, herniography is typically reserved for hernias that are difficult to diagnose and that were undetected by other diagnostic modalities.

Use of CT imaging for the diagnosis of hernias will provide additional information that may not have been previously identified during physical examination, ultrasound, or herniography. This was apparent in a study of 24 patients with possible abdominal wall hernias who had a CT scan and subsequent surgery. Two radiologists read the scans separately with an inter-observer variation of 0.87. It was found that CT scan evaluation for abdominal wall hernias had a sensitivity of 83% for both radiologists. However, the two differed with specificities 67% and 83%. The authors recommend the use of oral contrast and having the patient perform a Valsalva maneuver during the CT study to increase intra-abdominal pressure so as to accentuate the abdominal wall defect. (20) The use of the new multidetector CT scans that are used today can provide further information regarding the detailed anatomy of the inguinal region that can aid in the diagnosis of groin hernias.(21)

The use of dynamic magnetic resonance imagining (MRI) may provide additional anatomic detail of the groin area and assist with the diagnosis of a groin hernia without the exposure to radiation and provides high-quality soft tissue images. A feasibility study by van den Berg used MRI to evaluate healthy individuals compared to patients with known groin hernias. MRI was found to have a diagnostic accuracy rate of 84.6%.(22)

Accurate identification of a femoral hernia is challenging on physical examination alone. The use of multiple diagnostic modalities may be needed to make the correct diagnosis. Therefore, the

use of ultrasound, herniography, CT scan, and MRI should be carefully considered.

TREATMENT

What is the optimal surgical approach and repair of groin hernias?

Direct and indirect inguinal hernias are routinely repaired via an inguinal incision with the use of mesh. The use of laparoscopic hernia repair with mesh may be used for cases of recurrent inguinal hernias.(1)

The repair of femoral hernias has evolved over the years. Early on repairs typically consisted of reapproximation of attenuated tissue with suture, but recurrence rates were high and the need for subsequent surgeries was common. The surgical repair of the femoral hernia was greatly advanced by Dr. Lichtenstein.(23) Concerned about the high recurrence rates reported after femoral herniorrhaphy, he developed a new technique for repair. Approaching the femoral hernia from below the inguinal ligament (femoral approach), the femoral canal can be obliterated by use of a cylindrical polypropylene prosthetic plug inserted into the femoral canal after reduction of the femoral hernia sac. It is then secured distally with sutures, thus occluding the defect between the lacunar ligament medially and femoral vein laterally. This technique was applied to 22 femoral hernia repairs, and none recurred in a follow-up period from 1 to 5 years. Swarnkar et al. introduced the use of a conical polypropylene mesh-plug. In a review of cases from August 1997 to January 2003, 42 patients (31 elective and 11 emergent repairs) had their symptomatic femoral hernia repaired via the open, low approach. A conical polypropylene mesh-plug was inserted into the femoral canal after the hernia sac was reduced and closed. The mesh-plug was held in place by surrounding tissues; no sutures were used. Twelve patients had a median 2-year follow-up with no recurrences identified.(24) The preperitoneal posterior approach was used by Nyhus and colleagues, who conducted a review of their cases from November 1955 to November 1992. Prior to 1975, the repair was a reapproximation of attenuated tissue with suture. In 1975 they began using mesh for recurrent hernias with a re-reoccurrence rate of less than 2% for both inguinal and femoral hernias repairs. Overall for femoral hernias, this group had a 1% recurrence rate over the 37 years.(25)

The principles of McVay's Cooper ligament repair have been applied to femoral hernia repairs. In a review of cases from 1959 to 1984, Dr. Rutledge used this technique to repair direct, indirect, and femoral hernias. He reported a 0% recurrent rate of 31 femoral hernia repairs with an average of 9.1-year follow-up. He stated that he occasionally used mesh, although he did not specify in which cases he did so.(26) A retrospective chart review study by Naude et al. from February 1990 to June 1995 identified 22 patients with femoral hernia, 13 of which had a McVay repair. Nineteen of the 22 patients required emergent repairs. Postoperative complications included the following: three patients developed pneumonia, two wound infections, one deep venous thrombosis, and one death. They stated that their recurrence rate was unable to be assessed.(14)

Gönüllü applied a larger piece of polypropylene mesh to extended areas where a hernia may develop. He applied this through a standard inguinal incision. The technique was used in 28 patients with femoral hernias (19 elective and 9 emergent) from March 1988 to January 2004, with an average 40 months follow-up. Two patients developed postoperative urinary retention; there were no infections, seromas, or recurrences. Although the technique described was applied to repair femoral hernias, Gönüllü suggests it may be used to repair concomitant inguinal and femoral hernias.(27)

Another study evaluated 257 patients from January 1998 to January 2003 who had an open hernia repair utilizing a precut polypropylene sheet of mesh tailored to specific dimensions of the inguinofemoral area. Preoperative diagnosis of a femoral hernia was made in 23 patients, but an additional 39 patients who were initially diagnosed with an inguinal hernia were identified to have a femoral hernia at the time of surgery. This is not uncommon. To protect from the development of future femoral hernias, a specially shaped mesh was used to cover all potential hernia sites. There were no recurrences with follow-up ranging from 1 to greater than 5 years.(28)

A retrospective chart review study from January 1996 to June 2004 identified 83 patients who underwent femoral hernia repair. Hernia repairs were either with the McVay repair or with the use of polypropylene mesh-plug. Thirty-six patients had emergent surgery secondary to incarceration or strangulation. Seventy-nine patients had a McVay repair and four patients treated with polypropylene mesh-plug repair. Twelve patients had complications: seven were a seroma, hematoma or wound infection. The other five complications were three with GI bleeds and pneumonia (one of these patients died), one renal failure, and one patient had pleural effusions and intra-abdominal yeast infection. Although the authors did not specify which repair had complications, they did report that there was one recurrence with the polypropylene mesh-plug and one with a McVay repair.(29)

The application of laparoscopic transabdominal preperitoneal (TAPP) technique for the elective repair of femoral hernias between June 1993 to November 1998 was evaluated by Hernandez-Richter et al. A total of 51 cases of femoral hernia were repaired using the TAPP technique. This included primary and recurrent repairs. The rate of complications and recurrences were evaluated. Overall, an 82% postoperative follow-up was at 2 weeks and 1 year. Complications in six patients included one with migration of the mesh and fistula to the bladder, one hematoma, one hematoma with nerve irritation, one intestinal obstruction and nerve irritation, one port site infection, and one intestinal obstruction. No recurrences were identified.(30) A retrospective review of case records by Yalamarthi et al. from January 1994 to December 2002 identified 15 patients, who had repair of their femoral hernia via the laparoscopic total extraperitoneal (TEP) technique. Fourteen patients had primary femoral hernia repair and one had repair for a recurrent femoral hernia. Seven had a previous open inguinal hernia repair. None of the patients reported any pain or chronic discomfort at a 13.9 month mean follow-up. One patient developed a direct inguinal hernia recurrence at 4 months, thought to occur secondary to placement of a small mesh at the initial surgery.(31)

As noted above, there are many different surgical approaches and types of repairs. Lichtenstein et al. described the femoral

approach and popularized the use of a cylindrical shaped poly-propylene mesh-plug inserted into the femoral canal after reduction of its contents. Swarnkar et al. used the same approach but introduced a conical shaped polypropylene mesh-plug mesh into the femoral canal. Through a transverse lower abdominal incision, the preperitoneal posterior approach was used by Nyhus and colleagues to reapproximate attenuated tissue with suture from 1955 until 1975 when they started to use mesh. Dr. Rutledge et al. used a low, oblique incision and performed a Cooper's ligament repair and occasionally used mesh. Gönüllü used a standard inguinal approach and applied a larger piece of polypropylene mesh to extended areas where a hernia may develop. Reyes-Devesa et al. used the standard inguinal approach and placed a precut polypropylene sheet of mesh tailored to specific dimensions of the inguinofemoral area to protect from the development of future femoral hernias and cover all potential hernia sites. Alimoglu et al. utilized the McVay repair or used a polypropylene mesh-plug. Hernandez-Richter et al. described the application of laparoscopic TAPP technique for the elective repair of femoral hernias and Yalamarthi et al. described the laparoscopic TEP technique.

The initial optimal surgical approach for direct and indirect inguinal hernias is via an inguinal incision with the use of mesh. Laparoscopic hernia repair with mesh may be reserved for cases of recurrent inguinal hernias so as to avoid the previous surgical field. This approach requires advanced laparoscopic surgical skills and equipment. Of the modern types of femoral hernia repair, no one technique is superior. Care must be given to the characteristics of the hernia, the patient's clinical conditions, and the need to prevent complications and hernia recurrence.

SPECIAL CONSIDERATIONS

What other factors should you be aware of regarding repair of groin hernias?

Five aspects of the diagnosis and treatment of inguinal and femoral hernias require special consideration. These are (1) the possibility of the need for emergency surgery, (2) mortality in emergent cases, (3) the use of ultrasound to assist in the identification and reduction of a hernia, (4) the prophylactic use of antibiotics, and (5) the development of a femoral hernia after an inguinal hernia repair.

Femoral hernia usually presents as a surgical emergency because of the high likelihood of incarceration and strangulation. A retrospective study from 1987 to 1989 looked at the incidence of strangulation of inguinal and femoral hernias and examined the "cumulative probability of strangulation in relation to the length of history." Of 476 hernias, femoral hernias accounted for 37, and 12 of these were strangulated. The probability of strangulation of femoral hernias was 22% at 3 months and 45% at 21 months compared to inguinal hernias 2.8% at 3 months and 4.5% at 2 years. Therefore with the high risk of incarceration leading to strangulation, all femoral hernias should be repaired emergently.(6)

Another area in which femoral hernias distinguish themselves from inguinal hernias is mortality. Nilsson et al. conducted a prospective study of the Swedish Hernia Register from January 1992 to December 2004. They studied all patients older than 15 years of age who underwent repair of a groin hernia to assess the mortality rate. A total of 107,838 groin hernia repairs were documented. Emergent repair of an inguinal hernia accounted for 5,280 (5.1%) cases compared to 1,068 (36.5%) of the femoral hernias. Although the risk of mortality in patients undergoing elective groin hernia repair is low, patients requiring emergent repair of their femoral hernias had a 7-fold increase in mortality and 20-fold increase in mortality if the surgery required a bowel resection.(32)

Femoral hernias commonly present as incarcerated or strangulated as noted above. Incarcerated inguinal hernia reduction with the use of ultrasound guidance has been described in the literature. Ultrasound can identify location and extent of the hernia defect and guide the physician to reduce an incarcerated inguinal hernia.(33) Although the use of ultrasound in the reduction of femoral hernias has not been evaluated in the literature, it may provide additional information regarding the femoral area and insight into the characteristics of a suspected femoral hernia. Another situation where ultrasound may be beneficial is in pregnant woman who presents with a groin mass. This mass may not be a femoral hernia but may represent varicosities of the round ligament of the uterus. Ultrasound may distinguish varicosities from a suspected femoral hernia.(34)

The use of preoperative prophylaxic antibiotics in clean cases is another consideration. The literature does not offer a clear recommendation. A meta-analysis evaluating the use of prophylactic antibiotics in preventing wound infection after mesh (polypropylene) repair of abdominal wall hernias was conducted. Six randomized controlled studies were identified dealing with 2,464 open inguinal and 43 femoral hernia mesh repairs. Aufenacker et al. concluded that the routine prophylactic antibiotic administration was not indicated for mesh repair of groin hernias, but they did not comment specifically on the differences between inguinal and femoral hernia rates of infection.(35) Another meta-analysis reviewing the same data concluded that there was a beneficial effect from prophylactic antibiotics in prevention of surgical site infections after mesh inguinal hernia repair.(36) Therefore, the surgeon needs to carefully assess the patient's risk for infection and administer antibiotics based upon that individual's risk.

As a final consideration, it has been noted that after inguinal hernia repair, there is an increased risk for the development of a femoral hernia. A retrospective chart review of the Danish Hernia Database by Mikkelsen et al. from January 1989 to July 2001 reviewed 34,849 groin hernia repairs. Of this group, 1,297 were femoral hernia repairs. Seventy-one patients (5.5%) from this group had a previous inguinal hernia repair. These researchers calculated the expected number of primary femoral hernias in this study to be 4.9. Therefore, the 71 femoral hernia repairs after inguinal hernia repair represented a 15-fold increase in incidence. Mikkelsen et al. concluded that these may have been missed at the initial inguinal hernia repair.(37)

In conclusion, the incidence of femoral hernia is low. A detailed history and physical examination combined with use of the state-of-the-art diagnostic modalities is essential to make the correct diagnosis. If the diagnosis of femoral hernia is made in the elective setting, then the surgical approach may be inguinal, infrainguinal (femoral), open preperitoneal, laparoscopic TAPP, or

laparoscopic TEP. Because the incidence of incarceration and/or strangulation of bowel and/or omentum is higher in femoral hernias at the time of presentation compared to inguinal hernias, the clinician needs to carefully and quickly investigate the possibility of compromised bowel. If after physical examination and utilization of laboratory and diagnostic studies there is a suspicion of compromised bowel, the patient requires emergent surgery. The surgical approaches and types of repairs described above may be used. However, if these approaches are not adequate to provide a thorough evaluation of the bowel and omentum, then an exploratory laparotomy is indicated.

Evidence-Based Recommendations for the Current Diagnosis and Treatment of Femoral Hernias

Diagnostic Modalities	Grade of Recommendation
Physical examination	1C
Herniography	2C
Ultrasound	1C
CT scan	1C
MRI	1C
Treatment Options	
Femoral approach with mesh:	
Cylindrical	1C
Conical	1C
Inguinal approach with mesh:	
Oversized	1C
Tailored	1C
TAPP with mesh	1C
TEP with mesh	1C

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54 Esophageal perforation
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CASE PRESENTATION
A 55-year-old man with history of alcohol abuse and binge drinking, who has been hospitalized several times in the past year for hemorrhagic gastritis and bleeding esophageal varices, was transported by ambulance to the emergency department. He presented as hypotensive, slightly mottled, confused, and complained of substernal chest pain. It is unclear as to how long he was down. Electrocardiograph showed sinus tachycardia. Chest X-ray (posteroanterior/lateral) demonstrated a left pleural effusion and mediastinal air. Thin barium swallow revealed extravasation into the left chest. The patient was aggressively hydrated with isotonic fluids in the intensive care unit (ICU) and taken to the operating room where he underwent a two-layer plication and wide pleural drainage. The patient spent 2 days in the ICU and was transported to the floor on fifth postoperative day. A Gastrografin esophagram revealed a persistent leak into the left chest that is drained by a left right-angled chest tube. The patient is hemodynamically stable with a white blood count of 10,000/mm³. He is managed by hyperailmentation and continued nasogastric tube (NGT) suction.

ESOPHAGEAL PERFORATION: HISTORICAL PERSPECTIVE

The signs and symptoms of esophageal perforation were first described centuries ago. In 1723, Hermann Boerhaave described an autopsy of Baron von Wassenaer. He detailed an episode of spontaneous esophageal rupture secondary to intense vomiting following excessive ingestion of food and alcohol.[1] Olson and Clagett [2] and Barrett [3] reported the first successful surgical repairs.

The mortality associated with esophageal perforation has steadily declined in recent decades. The major reasons are access to antibiotics and early recognition of the signs and symptoms of esophageal perforation. However, despite advances in both surgery and critical care medicine, perforation of the esophagus remains a diagnostic and therapeutic challenge. Given the varied nature of this disease, morbidity and mortality stems from the etiology of the injury, the location, and the delay in diagnosis and treatment.

EPIDEMIOLOGY

Iatrogenic injury to the esophagus is the most frequent cause of esophageal perforation.[4] Instrumentation, such as endoscopy, is responsible for 59% of events. Spontaneous perforations account for 15% of all cases. Other causes include: foreign body ingestion (12%), trauma (9%), operative injury (2%), tumor (1%), and other causes (2%).[4]

Iatrogenic: what types of instrumentation are involved and is this common?

In recent decades, there has been a continued increase in the incidence of iatrogenic esophageal perforation due to the increased use of invasive endoscopic technology. The types of instrumentation that can cause perforation include esophagoscopy, sclerotherapy, variceal ligation, pneumatic dilation, bougienage, and laser therapy.

In the normal esophagus, the most common site of injury is in the cervical esophagus within Killian's triangle. The triangle is formed by the inferior pharyngeal constrictor and the cricopharyngeus muscles. In this region, the posterior esophageal mucosa is unprotected by muscle and is only separated from the retroesophageal space by buccopharyngeal fascia. Cervical osteophytic spurs, kyphosis of the spine, or hyperextension of the neck can further increase the risk of perforation in this area. [5] Instrumental perforation also occurs in areas of anatomic narrowing such as the cricopharyngeus muscle (the upper esophageal sphincter), the impingement of the aortic arch, the crossing of the left main stem bronchus, and the distal esophagus just proximal to the gastroesophageal junction. Areas of biopsy and regions just proximal to strictures are also at increased risk for perforation.

Despite increased intervention over the last 30 years, the actual risk of esophageal perforation during flexible esophagoscopy remains low. It is estimated to occur at a frequency of 0.03% when compared to 0.11% when using rigid endoscopy. More importantly, if esophagoscopy is combined with dilation, there is an increase in the frequency of esophageal perforation.[6, 7]

Endoscopic sclerotherapy for esophageal varices leads to perforation in 1–6% of patients in which the sclerosing agent induces a transmural necroinflammatory response. The risk is reduced with a decrease in both the volume and concentration of the sclerosing agent. Perforation may also occur during endoscopic variceal ligation when the esophageal mucosa is caught and torn between the overtube and the endoscope.[8]

Esophageal perforation can result from a variety of other iatrogenic causes. Perforation has been well documented during pneumatic dilation for achalasia with a frequency of 1–5%, the risk of which rises with higher inflation and previous pneumatic dilation.[9, 10] Other forms of esophageal intubation that may result in perforation are placement of endotracheal tubes, [11] NGTs, [12] Sengstaken-Blakemore tubes, [8] or endoesophageal prostheses.[13]

As one would suspect, intraoperative iatrogenic esophageal perforation has been described in surgical procedures that are in close proximity or directly involving the esophagus. These procedures include: pneumonectomy, (14) cervical spine operations, (5) left atrial surgery, (15) transesophageal echocardiography, (16) vagotomy, (17) and hiatal hernia repair.(18)

Spontaneous esophageal perforation: where does this usually occur and why?

Boerhaave's syndrome is a spontaneous esophageal perforation that occurs after an episode of vomiting.(1) It is thought to occur from a constellation of events that culminate in a rapid increase in intraluminal esophageal pressure through the combination of a patent lower esophageal sphincter and a constricted upper esophageal sphincter. As such, a transmural rupture typically occurs in the left posterolateral wall of the esophagus approximately 2–3 cm proximal to the gastroesophageal junction. This region is inherently weak as the longitudinal muscle fibers taper before passing onto the stomach wall.(19) Boerhaave's syndrome was initially associated with alcohol ingestion, but it is also seen with bulimia and other forms of self-induced vomiting.

Foreign body: how often is surgical intervention required?

Foreign bodies cause perforation in areas of anatomic narrowing. It is thought that objects less than 2 cm in size may traverse the normal adult esophagus without issue.(20) When an object has entered the stomach, there is an 80–90% chance that the ingested foreign body will pass the gastrointestinal tract spontaneously. However, of those that require interventions, about 1% undergo open surgery, whereas the rest can be removed via endoscopic intervention.(21) Foreign bodies are more likely to obstruct the esophagus if a stricture is present.

Trauma: what portions of the esophagus are involved in blunt and penetrating trauma?

Blunt esophageal trauma is extremely rare. The most common cause is related to high-speed motor vehicle accidents and it usually affects the distal esophagus.(22)

Penetrating esophageal trauma occurs mainly in the cervical esophagus with increased morbidity and mortality secondary to vascular, tracheal, and spinal cord injuries.(23) Studies have demonstrated that approximately 5–6% of transcervical injuries result in cervical esophageal injury.(24, 25) In contrast, the thoracoabdominal esophagus is less likely to be injured in external trauma given its centralized location.(19) A retrospective multi-institutional study spanning 10 years examined 405 patients who suffered from penetrating esophageal injuries.(26) It demonstrated that the two mechanisms of injury were gunshot wounds (78.8%) and stab wounds (18.5%). If taken as a whole, esophageal injury occurred in 4% of patients with an overall mortality of 19%.(26) The predominant location for injury was the cervical esophagus (57%) with the thoracic (30%) and abdominal (17%) esophagus being less frequently injured.(26)

Caustic agents: what is the pathophysiology of alkaline and acidic burns?

The extent, severity, and site of caustic esophageal injury are a consequence of the nature, concentration, amount, and duration of mucosal contact of the substance ingested.(27, 28) Inherent regions of narrowing are at increased risk of injury. In particular, caustic agents may result in a relaxed lower esophageal sphincter resulting in constant reflux into the distal esophagus.(29)

Injury secondary to caustic agents has been divided into three phases. The initial phase is characterized by inflammation, edema, and necrosis (2–3 days). The second phase, during which the esophagus is weakest and most prone to perforation, manifests as sloughing of esophageal debris with mucosal ulceration. This is accompanied by the development of granulation tissue, collagen deposition, and subsequent re-epithelization (3–4 weeks). During the third phase, cicatrization and stricture formation progress as the injured esophageal submucosa and muscularis are replaced with scar tissue.(19)

Alkaline and acid burns are the most common ingested caustic agents that result in esophageal injury. The manner and type of injury underlies the fundamental differences between these two agents. Ingestion of alkaline agents causes liquefaction necrosis and results in more esophageal than gastric injury. Acidic agents contact the esophageal mucosa causing coagulation necrosis.(19)

Other causes

It has been reported that esophageal perforation may result from erosion by primary or metastatic esophageal carcinoma, (30) Barrett's ulcers, (31) immunodeficiency, (32) and surrounding infection.(33) These causes are fairly rare in the absence of a stricture.

CLINICAL PRESENTATION

The clinical presentation of esophageal perforation varies and may be difficult to diagnose. It is highly dependent on the cause and location of the injury, the size of perforation, extent of contamination, time delay from injury, and symptoms of confounding injuries. The diagnosis can be difficult given that the presentation may mimic a myriad of other conditions including: myocardial infarction, pancreatitis, peptic ulcer perforation, aortic aneurysm dissection, spontaneous pneumothorax, empyema, or pneumonia. (4) Symptoms commonly associated with esophageal perforation include chest pain, dysphagia, dyspnea, subcutaneous emphysema, epigastric pain, fever, tachycardia, and tachypnea.(4)

Cervical: is cervical perforation less morbid than intrathoracic perforation?

Perforation of the cervical esophagus is generally less severe than perforation of the thoracoabdominal esophagus. Contamination of the mediastinum by oropharyngeal flora via the retroesophageal space is limited in part due to the esophageal attachment to the prevertebral fascia.(34)

Those patients who suffer from perforation of the cervical esophagus may present with neck pain, cervical dysphagia, dysphonia, or bloody regurgitation. On physical examination, it is common to encounter subcutaneous emphysema. This is seen nearly 95% of the time with chest plain film.(35)

Thoracic: how do patients present with intrathoracic perforation?

Unlike perforation of the cervical esophagus, intrathoracic perforations rapidly contaminate the mediastinum. The ruptured contents extend into the pleural cavity; typically right-sided with proximal esophageal perforation and left-sided with distal esophageal perforation. If the integrity of the pleura is maintained, the gastric contents disseminate in the mediastinum and produce an intense inflammatory response and cytokine activation. This results in mediastinitis characterized by mediastinal emphysema, inflammation, and eventually cervical subcutaneous emphysema. This initial chemical reaction is further propagated by bacterial invasion and mediastinal necrosis leading to pleural effusion after rupture of the mediastinal pleura. With the physiologic negative intrathoracic pressure, esophageal contents are drawn into the pleural space causing further sequestration of fluid, hypovolemia, and sepsis.(36)

Patients with intrathoracic esophageal perforation may present with retrosternal or chest pain lateralizing to the side of perforation, tachycardia, tachypnea, fever, and leukocytosis. On physical examination, a systolic crunching sound, Hamman's sign, may be heard to the left of the sternal border and cardiac apex. The presence of subcutaneous emphysema is detected in approximately 30% of patients as compared to 60% of patients with cervical esophageal perforation.(35) Of note, the combination of subcutaneous emphysema, vomiting, and chest pain comprise Mackler's triad, a pathognomonic sign for esophageal perforation.(19)

Abdominal: how do patients present with intra-abdominal perforation?

Perforation of the intra-abdominal esophagus results in gross contamination of the peritoneal cavity. Similar to intrathoracic perforations, accelerated inflammatory reaction and cytokine activation combine with bacterial invasion creating rampant peritonitis.

Patients may present with dull epigastric pain radiating to the back if the perforation is posterior and communicates with the lesser sac.(19) However, most patients present with sharp epigastric pain, peritonitis, and shoulder pain due to irritation of the diaphragm. As with intrathoracic perforations, abdominal esophageal perforation creates a constitution of symptoms that include tachycardia, tachypnea, fever, and leukocytosis.

DIAGNOSTIC OPTIONS

As previously mentioned, the clinical presentation of esophageal perforation is highly dependent on the etiology and location. The diagnosis, as with all serious disorders, begins with a careful but expedient history and physical examination. Although difficult at times, it is imperative that the diagnosis be made in a timely manner. Clinical suspicion, combined with imaging, laboratory analysis, and in some cases, direct visualization serves, to confirm or refute the diagnosis of perforation.

Plain radiography: how accurate and reliable are plain films for diagnosing perforation?

Radiographic studies play a significant role in the establishment of the diagnosis of esophageal perforation. In the case of cervical esophageal perforations, a plain film of the lateral neck may demonstrate air in the prevertebral fascial planes before it is detectable by chest radiograph or physical examination.(37) If a thoracic or abdominal, esophageal perforation is suspected, an upright abdominal along, with a posteroanterior and lateral chest radiograph, should be obtained.

A chest plain film may suggest esophageal perforation in 90% of patients, but it may be normal if taken immediately following the injury. It has been reported that soft tissue and mediastinal emphysema requires at least 1 hour to develop after perforation. Pleural effusions and mediastinal widening evolve over several hours.(37) It stands to reason that if plain films demonstrate a pleural effusion, pneumomediastinum, subcutaneous emphysema, hydrothorax, pneumothorax, or subdiaphragmatic air, the suspicion for esophageal perforation increases. However, if the plain film is normal shortly after a suspected esophageal injury, it needs further workup.

Contrast esophagography: does negative esophagography rule out a perforation?

Contrast esophagography is the study of choice for the diagnosis of esophageal perforation. It has an overall false-negative rate of 10%.(19) Two forms of contrast are available to decipher the presence and location of a perforation. Gastrografin, being water-soluble, has traditionally been the initial contrast of choice. This stems mainly from its rapid absorption after extravasation through the perforation. However, if aspirated, Gastrografin can induce a severe necrotizing pneumonitis and pulmonary edema. Of note, Gastrografin extravasates in only 50% of cervical and 75% of thoracic perforations.(38)

In the event that no perforation is detected with a water-soluble agent, serial dilute barium esophagography should be performed. Dilute barium should be used exclusively in patients at high risk for aspiration or if a tracheoesophageal fistula is suspected.(38) Barium has a higher density and better mucosal adherence than Gastrografin. Therefore, it may demonstrate smaller esophageal perforations missed by Gastrografin.(19) Barium will detect 60% of cervical and 90% of thoracic perforations.(35, 39)

A negative result with persistent suspicion of perforation requires serial repetition of barium contrast esophagography. A negative result cannot definitively rule out a perforation. An accurate diagnosis may require computed tomography (CT), esophagoscopy, or both.(4)

Computed tomography: What are the indications and reliability of CT for diagnosis perforation?

A CT serves as an important adjunct in diagnosing esophageal perforation. This modality is useful in confirming a diagnosis of esophageal perforation in patients where there is a high index of suspicion, an inability to undergo esophagography, or an atypical presentation. Findings on CT that are suggestive of esophageal perforation include mediastinal or extraluminal air, esophageal thickening, pneumomediastinum, esophagopleural fistula, pleural effusions, abscess cavities adjacent to the esophagus, and perceptible communication of air-filled esophagus with an adjacent mediastinal air-fluid collection.(40, 41) The CT is also useful when a malignancy is suspected. If a patient is not able to drink the contrast, it can be delivered via a NGT placed in the proximal esophagus.

Esophagoscopy: should a rigid esophagoscopy be performed to definitely rule out perforation?

Flexible esophagoscopy provides direct visualization of the perforation. In emergent evaluation of a traumatically perforated esophagus, flexible esophagoscopy is associated with 100% sensitivity and 83% specificity.(42) Arguments against the use of esophagoscopy stem from the possibility of missed perforation and the potential to convert a small mucosal or submucosal tear into more significant perforations during air insufflation.(43) If flexible esophagoscopy is performed, it must be done by an experienced endoscopist. Most general and even thoracic surgeons do not have a significant experience with rigid esophagoscopy and should not attempt it to visualize a perforation.

Pleural fluid analysis: what tests are useful in the acute workup of a possible perforation?

A CT is useful in localizing pleural fluid collections and guiding drainage catheter placement.(40, 41) In pleural fluid collected by thoracentesis, the presence of undigested food, a pH of less than 6.0, or an elevated salivary amylase level can confirm the diagnosis of esophageal perforation.(44) For patients with a large pleural effusion, a chest tube with enteric drainage is diagnostic.

TREATMENT OPTIONS

Therapy for esophageal perforation needs to be tailored to the patient. In addition to the age and baseline health of the patient, the damage to surrounding tissues and the presence of underlying esophageal pathology are important in directing initial therapy.(45) The goals of treatment include prevention of further contamination, elimination of infection, restoration of gastrointestinal integrity, and establishment of nutritional support. (46) Successful management of a thoracic perforation requires the following:

1. Debridement and drainage of the pleural spaces;
2. Control of the esophageal leak;
3. Complete reexpansion of the lung;
4. Prevention of gastric reflux;
5. Nutritional support; and
6. Antibiotics.

Timing of surgery: what is the impact of a delay in surgical intervention?

The time interval from esophageal perforation to treatment is a significant predictor of outcome. Despite advances in antibiotic therapy and critical care medicine, a delay in treatment of greater than 24 hours is associated with an increase in morbidity and mortality.(44) A recent meta-analysis of 390 patients from 11 series reported an overall mortality of 14% (0–28%) when treatment was initiated within 24 hours compared to 27% (0–46%) when treatment was delayed by more than 24 hours.(4)

OPERATIVE STRATEGIES

Surgical intervention includes the following strategies: primary closure with or without buttressing repair, esophagectomy with immediate versus delayed reconstruction, esophageal exclusion and diversion, T-tube placement and drainage, and drainage alone.

The selection of the appropriate surgical approach relies heavily on the location of the perforation and the clinical situation. The surgical approach best suited for a cervical perforation is through a cervical incision. This is usually easier on the left side and can be done through a standard cervical exploration along the anterior border of the sternocleidomastoid muscle. For a middle third perforation, a right thoracotomy in the fourth or fifth intercostal space provides an excellent exposure. Distal esophageal perforations are best approached through a left thoracotomy in the seventh intercostal space. An upper midline laparotomy is used to reach the abdominal esophagus and for enteric feeding access.(4)

PRIMARY REPAIR

Cervical exploration: what incision provides the best exposure?

Neck exploration is the correct approach for cervical esophageal injuries as well as injuries to the proximal one-third of the thoracic esophagus. The majority of cervical esophageal injuries should be approached via the left neck. The patient is placed in the supine position and a shoulder roll is placed beneath the scapulae to extend the neck, and the arms are tucked to the sides. The patient's head is rotated slightly to the right to provide optimal exposure of the left neck.

In the absence of distal obstruction, it is not necessary to repair a difficult to expose cervical esophageal injury, as the lesion will likely heal with adequate external drainage. However, the perforation should be primarily repaired if it is readily identified. For repair; a 40–46 Fr Maloney bougie is passed to prevent narrowing of the esophagus; a vertical esophageal myotomy is performed to expose the entire extent of the mucosal injury; the mucosal tear is repaired with interrupted 4–0 absorbable suture; the muscularis reapproximated with interrupted 3–0 suture.

The bougie is removed, and a NGT is inserted and guided into the stomach.

If the cervical esophagus cannot be primarily repaired, the wound is left partially open, packed, and allowed to granulate. A thin barium esophagogram is usually performed between postoperative days 5 and 7.

Thoracic exploration: is it safe and appropriate to perform a primary esophageal repair if greater than 24 h have passed since the time of perforation?

The surgical treatment of choice for an otherwise normal thoracic esophageal perforation is primary repair. It is imperative that all necrotic tissue is debrided. This usually includes a significant amount of the mediastinal pleura. It may also require decorticating the lung. A NGT is helpful in identifying the esophagus. The esophagus needs to be mobilized and necrotic esophagus is debrided carefully back to viable, bleeding tissue. The authors like to use a Penrose drain to help retract and fully mobilize the esophagus. Once the perforation has been identified and debrided, it is imperative to perform a vertical esophageal myotomy. Only by opening the longitudinal and circular muscle layers, can the full extent of the mucosal injury be appreciated. It can be quite surprising how much longer the mucosal defect is than the initially identified external defect in the muscle. After achieving the proper exposure, the esophageal mucosa should be reapproximated with interrupted sutures (4.0 Vicryl of PDS). The esophageal muscle can usually be closed as a second layer (3.0 silk).(47)

Many different tissues have been used to reinforce the primary repair site: thickened pleural flap, (48) omental onlay graft, (49) rhomboid and latissimus dorsi muscles, (50) diaphragmatic pedicled graft, (51) pedicled intercostal muscle, and pericardial fat pad. In the case of traumatic cervical perforation, the sternohyoid, sternothyroid, and sternocleidomastoid muscles may be incorporated.(23) The authors prefer to use an intercostal muscle, which is harvested during the thoracotomy. It can be done in less than 15 minutes and provides an excellent coverage, even in the case of a long perforation. Regardless of what flap is used, it is imperative to have a well-vascularized flap and to fix it to the repair.

Many surgeons continue to believe that primary repair following a delay in diagnosis of greater than 24 hours should be avoided and the patient should be diverted.(39, 52) However, primary repair offers the greatest probability of survival regardless of the time between esophageal perforation and treatment. (47, 53) Whyte et al. analyzed 22 patients who underwent primary repair without reinforcement. This was done regardless of the interval between perforations and repair. They reported a 5% mortality despite the fact that 41% of patients were treated after 24 hours.(47) Wright et al. reviewed 28 patients with esophageal perforation who underwent primary repair with reinforcement. They reported an overall mortality of 14% that included 46% delayed repairs of greater than 24 hours.(53) We strongly believe that primary repair is the treatment of choice for the vast majority of esophageal perforations regardless of the time from perforation. The key is to debride the necrotic tissue and identify the

full extent of the mucosal injury. The area should be drained and the authors also believe in placing a gastrostomy with a limb for jejunal feedings. Some surgeons do not want to make a gastrostomy in fear that they may need the stomach as a conduit if the repair fails and an esophagectomy is necessary. It is imperative to remember that primary repair should be avoided if there is extensive necrosis that prohibits reapproximation of viable tissue for patients with an esophageal malignancy and for those with a distal stricture.

In those patients where perforation of the esophagus is complicated by underlying pathology or distal obstruction, further evaluation is needed prior to engaging in primary repair. Primary repair with failure to relieve a distal obstruction is doomed to fail. However, treatment of both the perforation and distal obstruction can significantly reduce the mortality.(54) Treatment for patients with perforations secondary to dilation for achalasia involves both primary repairs with or without reinforcement, along with esophagomyotomy opposite to the side of perforation.(55) When perforation occurs in the presence of severe gastroesophageal reflux, an antireflux procedure should be attempted and used to bolster the esophageal repair. In the case of thoracic perforation, a Belsey Mark IV repair is used, and a Nissen funduplication is recommended for abdominal repairs.(4)

Resection and diversion: what are the indications for esophageal diversion?

When extensive mediastinitis or underlying esophageal pathology prevent primary repair during an initial presentation, surgical options include esophageal resection with immediate or delayed reconstruction, or exclusion and diversion. In cases associated with known megaesophagus from achalasia, carcinoma, caustic ingestion, or severe undilatable reflux strictures, esophagectomy should be considered.(19) However, the surgeon needs to balance the stability of the patient with the possible treatment options. An esophagectomy is contraindicated in a hemodynamically unstable patient. When considering esophagectomy, the approach is dictated by surgeon's experience, the interval from perforation to diagnosis, the severity of mediastinal inflammation, and the extent of pleural contamination. (56, 57) A transthoracic approach is usually required to adequately decorticate the lung and debride necrotic tissue. This can be followed by a staged reconstruction or a cervical anastamosis to bring the anastomosis out of a grossly contaminated bed.

Exclusion and diversion techniques are usually reserved for patients with extensive mediastinal contamination, a severely devitalized esophagus, or when the patient is unable to tolerate definitive repair or resection.(58, 59) Traditional techniques involve closure of the perforation, diversion, and mediastinal and pleural drainage. A cervical esophagostomy is created for proximal diversion and should be kept long to facilitate future reconstruction. This is usually performed via the left neck, and the esophagus can be tunneled subcutaneously to exit just inferior to the clavicle. Distally, a liner stapler can be used for exclusion and a gastrostomy tube is placed. The goal is to prevent further contamination and establish enteric access. This technique has evolved and is well described by Fell.(60)

T-tube drainage is advocated in situations where esophageal injuries cannot be repaired or if the patient is unable to tolerate

definitive repair or resection at the time of surgery.(46) Bufkin et al. performed a retrospective review of 54 patients with esophageal injury, 12 of which were unable to be repaired. Of the 12 patients, three were treated with T-tube drainage for a period of 23 weeks to divert all secretions and allow time for the surrounding tissues to heal. When placing the T-tube in the esophagus distal to the perforation, the long arm is directed toward the stomach, with the short arm in the esophagus proximal to the site of injury. The T-tube should then be brought out through a separate incision and secured laterally away from the aorta. A laparotomy is performed to create a gastrostomy for nutritional support.(46) It has been reported that T-tubes may lead to chronic fistula formation but these can be managed successfully. The T-tube is an excellent option for a truly unstable patient.

Drainage alone is usually reserved for small or contained cervical esophageal perforations. It can be used with caution down to the level of the carina.(46) In cases of thoracic and abdominal perforations, drainage alone is contraindicated due to the continued contamination that will occur.

Endoscopic stenting: is esophageal stenting an acceptable option for esophageal perforation?

Endoscopic esophageal stenting has seen tremendous growth and application over the last 25 years. The indications for endoluminal prosthesis include anastamotic tumor recurrence after surgery, extrinsic compression caused by mediastinal tumors, tracheoesophageal fistula, and benign esophageal strictures.(30, 61, 62) A recent published series on 15 consecutive patients who, suffering from spontaneous or iatrogenic esophageal perforations were treated with endoluminal stents. They demonstrated successful application in 14 patients with discharge to home and healed perforation. One patient died 6 days after stent insertion from aspiration pneumonia. The study asserted that once the diagnosis of esophageal perforation is established, endoluminal stenting should be applied fastidiously so as to avoid further mediastinal contamination. In general, patients are discharged with the stents in place and return for re-evaluation and stent removable within the 30–60 days. Stent migration is a problem that requires prompt identification and repositioning. The site of perforation is important in determining stent deployment with efforts made to avoid stenting at or above the upper esophageal sphincter or across the gastroesophageal sphincter. Stenting is currently not the first-line therapy for the majority of esophageal perforation. However, it can be helpful in a high-risk surgery patient with a good proximal and distal landing zone.

Non-operative management: what are the indications for non-operative management?

A non-operative approach for esophageal perforation is appropriate for a select group of patients with minimal mediastinal contamination and contained perforation. It is imperative that patients be hemodynamically stable and have a perforation that drains back into the esophagus or is contained. This method involves oral hygiene, complete cessation of oral intake, broad-spectrum antibiotics, and parenteral nutrition. Most people feel that NGT placement is an essential component of non-operative management; however, the tube needs to be placed carefully to avoid making the injury worse.(63)

Retrospective analyses have demonstrated that non-operative strategies are most successful when the perforation is instrumental or in the cervical esophagus, when detected early, and with small contained perforations.(4) In deciding which cases are best managed by non-operative treatment, the following criteria have been suggested: (39, 56, 64)

1. Early diagnosis;
2. Leak contained within the neck or mediastinum;
3. Drainage back into the esophageal lumen as evidenced by contrast imaging;
4. Injury in healthy, non-diseased tissue;
5. No distal obstruction;
6. A stable patient; and
7. Availability of contrast imaging and an experienced thoracic surgeon.

CASE PRESENTATION AND SUMMARY

The clinical scenario presented at the beginning of this chapter illustrates several important issues regarding the diagnosis and management of esophageal perforation. The first is the importance of rapid diagnosis and resuscitation. The presence of left pleural effusion and mediastinal air in this patient are strongly suggestive of an esophageal perforation. The contrast esophagogram is the test of choice to confirm the diagnosis and demonstrated a classic Boerhaave's tear in the distal esophagus draining into the left chest. The patient was aggressively and expeditiously resuscitated prior to going to the operating room. This can usually be accomplished in 1 or 2 hours, and a chest tube can be inserted to reduce continued soilage. In the operating room, a double lumen endotracheal tube was placed and a seventh interspace left thoracotomy was used for exposure. An intercostal muscle flap can be harvested during the thoracotomy. The pleura and mediastinum were debrided and the distal esophagus was mobilized. The perforation was visualized and the esophagus was debrided. A myotomy was performed to expose the entire mucosal tear and a two-layer repair was performed with an intercostal muscle flap placed as a buttress. The pleural space was copiously irrigated and drained with two 28 Fr chest tubes. A gastrostomy tube with a jejunal limb was placed as well.

Postoperatively, the patient appeared to do well. The pleural drainage was serous and he was transferred out of the ICU. The follow-up esophagogram showed a persistent leak that was well drained by the chest tube and the patient was doing well clinically. A chest CT scan is useful to ensure that there are no undrained collections and that the lung is completely re-expanded. If a collection is found, a CT-guided pigtail catheter can be very helpful. This patient should be managed by continued drainage of the gastrostomy and feeding via the jejunal limb. The right angle tube is left in place and taken off suction as long as the lung is completely re-expanded. A repeat swallow study 5 days later is likely to

show that the perforation is healed. The advantages of the feeding tube and good drainage are that the surgeon is not pressed to reoperate as long as the patient is stable. If the repeat swallow shows a continued leak in this stable patient, options include a removable stent or treatment of a controlled fistula. The chest tube can be slowly withdrawn and the leak should heal provided that there is no distal obstruction. It is imperative to remember that the algorithm changes if the patient shows signs of sepsis. It is also important to look at the esophagograms to be sure that there is no distal stricture or obstruction that will prevent the small leak from healing.

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Evidence Basis for Acute Intestinal Obstruction

There are no randomized controlled trials to support any aspect of this topic.

55 Acute upper gastrointestinal bleeding
Kimberly Joseph

A 35-year-old female presents to the emergency department with abdominal pain, hematemesis, and postural hypotension. She has a history of rheumatoid arthritis and is on chronic nonsteroidal anti-inflammatory drug (NSAID) therapy. Two large-bore intravenous (IV) bags are placed and isotonic fluid is administered. The patient's admitting hematocrit is 30%; her **international normalized ratio** (INR) is 2.8 with a **partial thromboplastin time** (PTT) of 80 s; her platelet count is 70,000. Urgent upper gastrointestinal endoscopy (EGD) is performed, revealing clotted blood in the stomach, diffuse gastritis, but no distinct bleeding site or ulcer. The patient is started on an IV proton pump inhibitor (PPI) infusion and receives 4 units of fresh frozen plasma (FFP), 2 units of packed red blood cells (PRBC), and 5 units of platelets, along with intermittent nasogastric tube (NGT) lavage. Despite this therapy, the patient's clinical and laboratory assessment continues to suggest on-going bleeding. Repeat EGD demonstrates a 2-cm bleeding ulcer at the incisura of the lesser curve of the stomach. Attempts at endoscopic control of the bleeding are unsuccessful. She is taken to the operating room where she undergoes truncal vagotomy and pyloroplasty with excision of the ulcer.

EPIDEMIOLOGY OF ACUTE UPPER GASTROINTESTINAL BLEEDING

Acute upper gastrointestinal bleeding (AUGB) remains a common clinical problem resulting in significant morbidity/mortality and cost. Incidence estimates range 40–150 cases per 100,000 population per year in Western countries (1, 2) and it accounts for 200,000–300,000 hospital admissions per year.(1) The estimates on cost to society range $750–$900 + million per year.(3, 4) Overall mortality remains largely unchanged over the past several decades, estimated to range 5–15%.(5–7)

Despite a lack of significant mortality reduction, improvements in the care of AUGB—resuscitation, critical care, pharmacology, and particularly endoscopic and interventional radiographic techniques—have led to decreases in rates of rebleeding and need for surgery (which is indicated only after less invasive techniques have failed). This chapter will discuss the causes of AUGB and common clinical presentations; supportive, diagnostic, and therapeutic options; and special considerations in the approach to patients with this entity.

Etiology of Acute Upper Gastrointestinal Bleeding: Non-Variceal Bleeding

Causes of AUGB are commonly divided into two categories: variceal and non-variceal. Non-variceal causes of AGUB include:

Peptic Ulcer Disease

This is the most common etiology of AUGB, estimated to cause 40–75% of all episodes.(8, 9) Clinicians should remember that this is also the most likely etiology of acute bleeding in a patient with a history of alcohol abuse and cirrhosis. The most common clinical complaint is epigastric pain; this can be difficult to differentiate from reflux disease, dyspepsia, biliary disease, pancreatitis, as well as angina. Duodenal ulcers, as opposed to gastric ulcers, are often characterized by burning/gnawing pain that occurs after eating, and is relieved with food or antacids; gastric ulcers typically do not respond to food intake. Patients with bleeding from peptic ulcer disease (PUD) may present with hematemesis, melena, hematochezia, or a combination of these, although hematochezia should direct the clinician more toward a lower GI source or variceal bleeding. The association of Helicobacter pylori and PUD was described in a seminal publication by Warren and Marshall in 1983 (10); this will be discussed later in the chapter.

Management of patients who present with AUGB due to PUD begins with adequate volume resuscitation and initiation of acid suppression therapy. PPI agents appear to be superior to other agents in this regard.(11–13) EGD remains a first-line mode for both diagnosis and therapy of bleeding ulcers. Surgery is reserved for those patients who have exsanguinating hemorrhage, who fail endoscopic and medical therapy, who have recurrent bleeding, and/or who have other complications of ulcer disease (perforation, obstruction, malignancy). Specific endoscopic therapeutic options and surgical approaches will also be discussed later in the chapter.

Mallory-Weiss Lesions

These are tears occurring at or near the gastroesophageal junction secondary to mechanical stress, most commonly induced by retching or vomiting. Despite this relationship, report of antecedent vomiting occurs in as few as 30% of cases to as high as 85%.(14–16) Hematemesis is a presenting symptom in 85–95% of cases.(15, 16) They account for 4–14% of findings in EGD done for acute bleeding (14) and usually present as single tears. The bleeding from these lesions is usually self-limited.(17)

Tumors

Any tumor occurring in the esophagus or stomach has the potential to bleed into the lumen for a variety of reasons—necrosis/erosion into local arteries, neovascularization, and radiation/chemotherapy. However, these entities contribute only a small percentage of episodes to the overall incidence of AUGB.

Reflux esophagitis

Although gastroesophageal reflux disease (GERD) is very common, it is unusual for it to present as bleeding except in special populations. Zimmerman et al. (18) described 248 patients presenting with AUGB due to esophagitis: 21.1% of episodes occurred in patients older than 80 years compared to 3.3% in patients

60–69 years old. Bleeding due to erosive and stress esophagitis/gastritis is also more common in the critically ill population as will be discussed later in the chapter.

Dieulafoy's Lesion

This lesion is an abnormal submucosal artery in the GI tract characterized by recurrent episodes of bleeding. The incidence is reported anywhere in the range 0.5–14%, occurring more commonly in older men.(19) The lesions are most commonly located in the proximal stomach; however, Treesaranuwattana and Khemati (20–22) have published case series and reviews documenting such lesions as occurring from the mouth to the colon. EGD with band ligation and epinephrine injection may be successful therapies for this lesion.

Infectious Causes

Infectious causes of AUGB are unusual outside of the immune-compromised population. In this latter group, upper gastrointestinal (GI) infections more commonly present with odynophagia/dysphagia as opposed to bleeding. Potential infectious causes of AUGB include herpes simplex virus, Cytomegalovirus, varicella zoster virus, human papilloma virus, human immunodeficiency virus, Candida, and other fungal and mycobacterial infections.

Vascular malformations, Arterial-enteric fistula, other causes

Hemangiomas, vascular malformations, and some inherited disorders such as Osler-Weber-Rendu syndrome may manifest themselves with acute bleeding. Vascular malformations are responsible for the majority of small bowel bleeding. Arterial-enteric fistulas, seen more commonly in the setting of trauma, cancer, or postoperatively, may present as massive intraluminal bleeding. In patients with biliary or pancreatic trauma/disease, hemobilia and hemosuccus pancreaticus must also be considered as a possible, if unusual source of bleeding.

Drug-induced enteropathy

Gastropathy/enteropathy resulting in AUGB can result from the use of a number of medications, including erythromycin, aspirin, and selective serotonin reuptake inhibitors (SSRIs). One of the classes of medications that have received attention are the NSAIDs. As with our patient described in the beginning of the chapter, the use of these medications may result in hemodynamically significant bleeding and ulcer formation. More than 70 million prescription and 30 billion non-prescription NSAIDs are sold yearly; for that reason, NSAID gastropathy is one of the most common serious adverse drug reaction events seen in the United States.(23) In the mid 1990s, the Misoprostol Ulcer Complications Outcomes Safety Assessment (MUCOSA) study (24) examined the outcomes of rheumatoid arthritis patients taking NSAIDS plus misoprostol versus placebo; there appeared to be significant protection afforded by those patients in the experimental group. However, once ulcers develop, PPIs appear to be superior to H2-receptor antagonists and misoprostol in promoting healing. (25) Also, even if the ulcer is felt to be related to NSAID use, the patient should be tested for H. pylori.

Much attention has been paid recently to the specific cyclooxegenase 2 (COX2) inhibitors. Studies have demonstrated that the incidence of ulceration seen on endoscopy in patients taking these medications approaches that of placebo, and is less than that seen in patients taking traditional NSAIDs.(26, 27) However, some questions have been raised regarding other safety concerns in patients who use these medications. Decisions regarding whether to prescribe these medications should be made on a case-by-case basis, weighing the risks/benefits to the individual patient.

Etiology of Acute Upper Gastrointestinal Bleeding: Variceal bleeding

AUGB from the sequellae of portal hypertension, namely variceal bleeding, carries a higher mortality and rate of recurrence relative to non-variceal causes of bleeding.(28) Causes of portal hypertension may be prehepatic (malignancy, hypercoaguable states, oral contraceptive use, chronic pancreatitis with splenic vein thrombosis), intrahepatic (chronic viral hepatitis, alcoholic liver disease) or posthepatic (Budd–Chiari syndrome, hepatic vein or inferior vena cava thrombosis, right heart failure, constrictive pericarditis). As in patients with PUD, patients with bleeding from portal hypertension may present with hematemesis, melena, hematochezia, or a combination of these. Clinicians should examine the patient for stigmata of chronic liver disease such as jaundice, splenomegaly, spider angiomata, and caput medusa, as the presence of these may suggest variceal bleeding as a more likely source. That said, the most common cause of AUGB in a patient with chronic alcohol use is PUD, as mentioned before. AUGB can also precipitate acute hepatic encephalopathy in patients with decompensated liver diseases. While it may be possible to manage a patient with certain non-variceal causes of AUGB in a step-down type of setting, patients with acute variceal bleeding should be managed in the intensive care unit (ICU). IV vasopressin (or an analog) in combination with nitrate preparations (29), along with Octreotide (30) have been studied in the early management of variceal bleeding; although both agents appear to have benefits, neither has been shown to convey a survival advantage.(30, 31) Endoscopic therapies are a mainstay of management of variceal bleeding once resuscitation has been achieved. For patients who fail pharmacologic and endoscopic therapy, transjugular intrahepatic portosystemic shunts (TIPS) are favored in the setting of hemodynamic instability. Surgical shunts are still performed in the emergency setting but much less often than in previous years.

INITIAL APPROACH TO THE PATIENT WITH ACUTE UPPER GASTROINTESTINAL BLEEDING

Resuscitation

As with any patient who presents in the setting of acute blood loss, the clinician should start with the "ABCs". Aspiration of bloody enteral contents can lead to rapid loss both of the airway and respiratory reserve. Further, as patients bleed into shock, alterations in sensorium may lead to inability to self-protect the airway. One should not be hesitant to secure the airway early in the resuscitation process. Fluid resuscitation should follow commonly recommended protocols: initial resuscitation should begin via a large-bore catheter with isotonic fluid. Note that if the suspected cause is variceal bleeding, normal saline is the fluid of choice. Standard laboratory studies should be obtained, such as hematocrit (although

Table 55.1 Components of The Rockall Scoring System for Prognostication of Upper GI Bleeding.

	SCORE			
	0	1	2	3
Pre-Endoscopy				
Age	▪ <60 years	▪ 60–79 years	▪ >80 years	
Shock	▪ Systolic BP> 100 and Pulse <100	▪ Systolic BP >100 and Pulse >100	▪ Systolic BP <100	
Comorbidity	▪ None		▪ Ischemic heart disease ▪ Cardiac failure ▪ Any major comorbidity	▪ Renal failure ▪ Hepatic failure ▪ Disseminated malignancy
Post-Endoscopy				
Diagnosis	▪ Mallory Weiss tear or ▪ No lesion seen and ▪ No stigmata of recent hemorrhage	▪ All other diagnoses	▪ GI malignancy	
Major stigmata of hemorrhage	▪ None or dark spot only	▪ Blood in upper GI tract ▪ Non-bleeding visible vessel ▪ Spurting vessel or adherent clot		

this value may not initially change) and coagulation studies. Failure to respond appropriately to crystalloid resuscitation and/or the presence of coagulation abnormalities should prompt the early transfusion of blood products. In addition to these studies, basic metabolic profiles, liver function tests, and ammonia levels may also be useful. Careful placement of a NGT for decompression should be performed, although no definitive evidence exists that lavage with room temperature or iced fluid prevents further bleeding. Plain radiographs may be useful in diagnosing aspiration pneumonitis or hollow viscus perforation.

Patients with AUGB should usually be admitted to a monitored setting, depending on clinical and endoscopic findings. Rockall et al. (32) proposed a scoring methodology that might identify patients who had a lower risk of rebleeding and/or mortality based on clinical and endoscopic findings on admission. In theory, these patients could be managed in a less intensive environment. Table 55.1 illustrates the components of the Rockall scoring system. Similar scoring systems have been developed and evaluated (33), including the Baylor bleeding score, the Cedars-Sinai predictive index, and the Blatchford score.

Initial pharmacologic therapy is somewhat dependant on the suspected/determined etiology and may be deferred pending endoscopic results. As previously mentioned, initiation of acid suppression therapy with IV PPI is indicated for bleeding from PUD or ulcers due to NSAID use. However, because the side effect profile of IV PPI is benign in the acute setting, the clinician may also consider its empiric use while awaiting endoscopy. Similarly, there is insufficient evidence to support the routine use of Octreotide in acute non-variceal bleeding; however, it may be useful (and not harmful) in the setting of uncontrolled bleeding while awaiting endoscopy. The use of vasopressin/terlipressin with nitrates as well as Octreotide has potential usefulness in the setting of variceal bleeding but remains controversial.

Table 55.2 describes a basic algorithm for the initial approach to the patient with AUGB.

Endoscopy: Timing Considerations and Therapeutic Options
The timing of endoscopy continues to be a source of controversy, although early endoscopy clearly aids in determining the etiology of AUGB. Parente et al. (34) prospectively assessed patients admitted for non-variceal AUGB over a 2-year period; the timing of endoscopy was divided into routine and "on call". Experience level of the endoscopist was also evaluated. The latter was found to be an independent prognostic factor in the outcomes that were measured, including rebleeding rate, transfusion requirements, and need for surgery. The timing of the endoscopy did not appear to exert a similar effect; the authors concluded that urgent endoscopy should be undertaken preferentially by a skilled endoscopist. Two other studies evaluating the timing of endoscopy in the emergency setting demonstrated conflicting results.(35, 36) Lee et al. demonstrated reduction in resource utilization and length of stay with urgent endoscopy. Bjorkman, however, was unable to show this advantage; it was felt that this might be due to the reluctance to discharge "low-risk" patients even after endoscopy suggested that they could be managed as outpatients. As the decision to admit a patient is often made prior to endoscopy, the literature regarding timing is difficult to evaluate. The Non-variceal Upper GI Bleeding Consensus Conference Group (37) recommends "early endoscopy" within the first 24 h with risk classification by clinical and endoscopic criteria.

In preparing a patient for endoscopy, the clinician should take several factors into consideration, including whether or not the airway needs to be definitively secured prior to the procedure. Correction of coagulopathy should be completed or at least in process by the time of EGD. During the procedure, the patient will usually require chemical sedation; the clinician should assure an environment in which the patient will be monitored according to standard American Society of Anesthesiology guidelines.

Therapeutic options during EGD depend upon the findings. In the setting of non-variceal bleeding, the literature does not clearly favor any particular injection or coaptive therapy over another.(37) Argon plasma coagulation is a noncoaptive method in which current is applied by means of ionized argon gas. Initial studies suggested an advantage with the therapy in terms of time to

Table 55.2 The Initial Approach to the Patient with Acute Upper Gastrointestinal Bleeding.

Resuscitation
Secure airway as needed
Isotonic Fluid
Laboratory studies—hematocrit, coagulation studies, and basic metabolic and liver profiles
Consider serologic test for H. pylori
Nasogastric and urinary catheter placement
Blood product transfusion as indicated by clinical/laboratory factors

Pharmacologic therapy
Consider empiric IV PPI
Consider IV octreotide
Consider IV vasopressin +/− nitrates for variceal bleeding

Endoscopy
Initial attempt at endoscopic control of bleeding within 24 h
Repeat endoscopy if initial attempt fails and/or rebleeding occurs

Radiographic evaluation and intervention
Consider nuclear medicine studies and/or angiography for bleeding not localized by endoscopy
Consider intra-arterial Vasopressin or embolization for non-variceal bleeding found on angiography
Consider TIPS for variceal bleeding

Surgical intervention
Reserve for patients who fail more conservative therapy
In unstable patients, focus should be on hemorrhage control, not definitive acid-reduction procedures
In the setting of bleeding due to ulcer disease: the location, type, and size of the ulcer should influence choice of operation

coagulation. However, a randomized trial comparing epinephrine injection plus heater probe coagulation versus argon plasma coagulation failed to demonstrate a clear overall advantage.(38) The use of hemostatic clips is also an option; however, a study by Lin et al. (39) demonstrated better control of initial bleeding with the heater probe compared with a particular brand of endoclip. Although it would be valuable to perform biopsies on suspicious-appearing gastric ulcers, this is recommended only if the ulcer is not actively bleeding and has no stigmata of a recent bleed. Testing should also be done for H. pylori.

In the setting of variceal bleeding, endoscopic band ligation and sclerotherapy are both options for therapy. Banares et al. in their meta-analysis (40) suggested that endoscopic therapy in combination with pharmacologic therapy (somatostatin and its analogs) achieved superior results compared to endoscopic therapy alone . After patients undergo initial treatment, it has been suggested that they should have follow-up endoscopy at 1–2 week intervals for repeat therapy until the varices are obliterated. Non-selective B-adrenergic antagonist agents are recommended to prevent bleeding in patients with portal hypertension, but have no role in the setting of active bleeding.

Special Endoscopy Considerations: Obscure Gastrointestinal Bleeding
A relatively new therapy exists for the endoscopic diagnosis of bleeding that is not obvious on EGD. Recent publications regarding "capsule endoscopy" (41–43) and "double-balloon" enteroscopy (DBE) (44–46) or a combination (47) suggest that these are viable options in the diagnosis of "obscure" bleeding, which is defined as bleeding of unknown origin that persists or recurs. The presence of hematemesis, suggesting a "true" AUGB, may in fact represent bleeding from the small bowel, which may be accessible with either capsule endoscopy and/or DBE. With capsule endoscopy, a sensor is placed on the patient's abdomen, and he or she is asked to swallow the capsule endoscope. The capsule transmits images to the sensor over a several hour period, which is then analyzed by the endoscopist. With double balloon enteroscopy, a special enteroscope with a balloon at its tip and an overtube, which also has a balloon, are inserted into the GI tract. Following this, the endoscope is advanced to a small distance in front of the overtube, and the balloon at the end is inflated. Using the assistance of friction at the interface of the enteroscope and intestinal wall, the small bowel is accordioned back to the overtube. The overtube balloon is then deployed, and the enteroscope balloon is deflated. The process is then continued until the entire small bowel is visualized. As both techniques are relatively new, information regarding complications and long-term outcomes is incomplete. Aspiration of the capsule is a potential complication of capsule endoscopy. DBE is felt by some to be unusually labor intensive, and complications of perforation and pancreatitis have been reported.

Radiographic Evaluation/Intervention in Acute Upper Gastrointestinal Bleeding
It is fair to say that the development of the TIPS has contributed enormously to the clinician's ability to manage bleeding due to portal hypertension, particularly in the unstable patient or in the patient with decompensated cirrhosis. The radiologist gains access to the hepatic vein under fluoroscopic guidance and creates a parenchymal tract between this system and the portal venous system. The tract is then dilated and a stent is placed. TIPS may be used as a bridge to transplantation; at least one small study has demonstrated a trend toward better survival and lower transfusion requirements in patients who underwent TIPS placement prior to transplant.(48) Complications of TIPS include acute thrombosis/stenosis of the shunt, shunt migration, or erosion of the shunt leading to portal–arterial of biliary-vascular fistula. As with certain surgical shunts, the occurrence of encephalopathy may also increase with TIPS.

In the setting of AUGB, the use of arteriography can be a useful diagnostic and therapeutic tool; EGD should be performed first, however, as this can direct the angiographic process and help avoid "total body" angiograms. The use of arterial embolization is commonly discussed with regards to massive lower GI bleeding. However, as mentioned previously, small bowel bleeding can present with hematemesis, mimicking causes of "true" upper GI bleeding. Small bowel bleeding can result from tumors, inflammatory bowel disease, vascular malformations, and angiodysplasia. In selected cases, intra-arterial vasopressin or embolic materials such as coils and Gelfoam may be useful if an isolated site of small bowel bleeding is identified. If nothing else, the procedure may be of use in directing a subsequent surgical intervention.

Barium contrast studies, such as small bowel follow-through and enteroclysis, are not recommended in AUGB. Such studies are insensitive in the acute setting and may interfere with angiography, nuclear medicine scanning, and endoscopy. They may be beneficial in evaluating recurrent or chronic bleeding.

Nuclear medicine scintigraphy is more sensitive at detecting slower rates of bleeding when compared to angiography. Although animal studies traditionally have suggested that bleeding rates as low as 0.04 ml/min can be detected via these techniques, clinical studies indicate that a slightly greater rate of bleeding is required. (49) The two standard agents used are technetium-99m-labeled sulfur colloid and technetium-99m-labeled erythrocytes. Both agents localize bleeding by extravascular accumulation. Although the usefulness of scintigraphic techniques continues to be debated, one area in which they are usually recommended above other techniques is when a Meckel's diverticulum is suspected.

Surgical Intervention in Acute Upper Gastrointestinal Bleeding

As with the patient described at the beginning of the chapter, some patients with AUGB fail endoscopic or radiographic therapies and require surgical intervention. A patient who rebleeds after initial endoscopy should undergo repeat endoscopy unless the bleeding has become life threatening. A recent study by Lau et al. (50) suggested that patients who underwent repeat endoscopy and attempt at hemostasis as opposed to surgery had decreased transfusion requirements, 30-day mortality, and ICU length of stay. However, patients who have ongoing bleeding after receiving 4–6 units of PRBC (the so-called "rule of 6") must be at least considered as operative candidates. Should a patient require an operation, the type of operation is dependent on: the stability of the patient; the location of the lesion; and the presence of other complications, such as perforation, obstruction, and/or malignancy. Hemodynamically unstable patients should undergo an operation that controls hemorrhage but minimizes operative time, recognizing that additional surgical intervention may be needed once the patient is stabilized. When bleeding is due to a gastric ulcer, one must consider the location of ulcer and whether or not it is associated with a hypersecretory acid state. The following should be considered:

Type 1 gastric ulcers are located on the lesser curve of the stomach at/near the incisura and are not usually associated with a hypersecretory acid state.
Type 2 gastric ulcers are a combination of two ulcers, one in the stomach and the other in the duodenum, and are usually associated with a hypersecretory acid state.
Type 3 ulcers are prepyloric ulcers. They are usually associated with high acid output.
Type 4 ulcers are located high on the lesser curve and are not associated with high acid output.
Type 5 ulcers (as seen in the patient described at the beginning of the chapter) are those induced by NSAIDS or aspirin and can occur anywhere in the stomach.

Patients who are hemodynamically stable with Type 1, 2, or 3 gastric ulcers and who have recurrent bleeding requiring transfusion are candidates for truncal vagotomy and distal gastric resection and gastroenterostomy (Billroth I or II). Hemodynamically

unstable patients with Type 1, 2, or 3 ulcers are candidates for truncal vagotomy and drainage procedure (e.g., pyloroplasty) in combination with oversewing/excision of the ulcer. Patients with Type 4 ulcers should undergo ligation of the left gastric artery, biopsy, and then oversewing of the ulcer. In the presence of perforation in an unstable patient, management of the perforation with a patch technique and oversewing of the bleeding site may be all that can be accomplished safely; a definitive procedure must wait until the patient is more stable.

Duodenal ulcers associated with the gastroduodenal artery should be treated with oversewing and a "three-point" ligation technique, consisting of proximal and distal ligation of the gastroduodenal artery as well as a horizontal mattress suture to control the transverse pancreatic branch of the artery. Another consideration with regards to the surgical management of bleeding ulcers is the size of the ulcer itself; generally ulcers more that 2 cm in diameter cannot be treated by oversewing alone and may require excision or gastric/duodenal resection.

Studies examining the outcomes of conservative versus more extensive surgical therapy have been performed, although the numbers of patients in the studies are small. Poxon et al. (51) reported a higher incidence of fatal rebleeding with conservative surgical procedures consisting of oversewing and H2 blocker therapy; however, it is possible that the results might have been different in the era of PPI use. Similarly, Millat et al. (52) reported lower rebleeding rates with gastric resection and ulcer excision. However, duodenal stump leak rates were relatively high, and mortality rates between the two groups were not significantly different. Rebleeding rates for procedures that leave the ulcer in situ may be as high as 40%.(53)

The type of vagotomy performed may also influence outcome. All vagal interruption procedures are associated with some degree of "dumping". Advocates of the proximal (highly selective) vagotomy point out that, since the antral innervation is preserved with the procedure, there is less of an effect on emptying of solid food. However, a truncal vagotomy is the preferred choice in an unstable or high-risk patient, as it is a technically easier and faster procedure to perform.

Surgical intervention in variceal bleeding should be reserved for patients classified as Childs-Pugh A or B with regard to cirrhosis. Childs-Pugh C patients have a very high operative mortality, and TIPS is the procedure of choice for these patients should they fail endoscopic and/or pharmacologic control. Surgical procedures for variceal bleeding can be generally classified into shunting and devascularization procedures. "Total" shunts, such as direct portocaval and interposition mesocaval shunts, divert the vast majority of blood away from the liver. Direct portocaval shunts are technically easier, but are associated with higher rates of encephalopathy. Interposition mesocaval shunts thrombose more easily. "Selective" shunts, such as the Warren splenorenal and Sarfeh portocaval interposition shunts either partially decompress the portal system or isolate the gastroesophageal (GE) junction varices from higher portal pressures. These are considered by some to be technically more difficult to perform. The Warren shunt is associated with increased ascites, and the Sarfeh shunt thromboses more easily. Nonshunt devascularization procedures, such as the Suguira procedure, involve

Table 55.3 Grade of Evidence for Selected Recommendations in the Management of Acute Upper Gastrointestinal Bleeding (AUGB).

Management Option	Grade of Recommendation
Pharmacologic therapy	
PPIs should be initiated for AUGB due to ulcer disease (11–13)	1A
Empiric use of PPIs prior to endoscopy may be useful(37)	2B
IV vasopressin with nitrate preparations in variceal bleeding may aid in hemorrhage control (29–31)	2B
IV octreotide/somatostatin analogues: not useful in non-variceal bleeding (37) useful in Variceal bleeding (29–31, 40)	–1C –1C
Endoscopy	
Initial endoscopy recommended within 24 h (34–37)	1A—although the definition of "early" varies, endoscopy aids in risk stratification and resource utilization
Repeat endoscopy if initial attempt fails or rebleeding occurs (37, 50)	1A
No single endoscopy injection or thermal coaptive therapy is superior to another in non-variceal bleeding(37–39)	1A
Endoscopic therapy combined with somatostatin analogues is superior therapy versus endoscopy alone in variceal bleeding (40)	1B
Helicobacter pylori	
Patients with AUGB should be tested for H. pylori (37, 56)	1A
Stress-related mucosal disease in the critical care setting	
The use of stress ulcer prophylaxis in the ICU setting should be influenced by specific risk factors and weighed against potential for medication-related complications (57–59)	1B

ligation of the varices using esophageal transection and gastric devascularization without affecting portal hypertension. They are effective in patients with portal thrombosis for controlling acute bleeding; however, collaterals inevitably develop, leading to high recurrence rates.

In the setting of "obscure" AUGB and bleeding that has not been diagnosed prior to operation, the surgeon faces a particular challenge. It is valuable, if possible, to use endoscopic or radiographic techniques preoperatively to attempt to localize the area of bleeding so that the subsequent operation can be as specific as possible. Alternatively, the surgeon can perform EGD or enteroscopy via a surgically created enterotomy intraoperatively to attempt to discover the site/area of bleeding. Subtotal/total gastrectomies or massive small bowel resections are to be avoided except in extreme circumstances.

In summary, surgical intervention for AUGB is much less common than in the past. However, surgeons should be involved early in the care of any patient who presents with risk factors that suggest poor prognosis or likelihood of rebleeding; such clinical factors would include age greater than 60 years, comorbidities,

shock, hematemesis, and requirement of greater than 6 units of PRBC for resuscitation. Additionally, endoscopic findings of large ulcers and major stigmata of bleeding suggest a higher likelihood of rebleeding. Surgical approaches vary with the etiology of the bleed, the condition of the patient, and the association of other pathology.

Helicobacter pylori infection and Acute Upper Gastrointestinal Bleeding

H. pylori infection is now felt to be the cause of most acute and recurrent ulcers, although the mechanism(s) by which it causes ulcer disease are not completely clear. It produces an intense local inflammatory response despite not invading the gastric mucosa. It disrupts the gastric secretory physiology, leading in to high acid secretion in some cases and low acid secretion in others. (54) The actual incidence of H. pylori in duodenal and gastric ulcers also remains unclear. At one time it was thought to be in the range of 90%, but a recent multicenter study put the prevalence at 73%.(55) There is general agreement that patients with active or past duodenal/gastric ulcers should be tested. If EGD is not planned, serologic tests may be used. Because antibodies remain detectable after the active infection is resolved, serologic testing is not useful to document eradication. The urea breath test and stool testing are also options; however, the former can be affected by the use of PPIs. If endoscopy is planned, biopsies may be taken to detect H. pylori. The rapid urease (RUT) tests that are used in this setting may be confounded by the use of antibiotic and PPIs. H. pylori has been implicated as a risk factor in the development of AUGB in the intensive care setting. (56) In the setting of acute bleeding, biopsy for RUT testing and histology have lower sensitivity; serologic testing may be more appropriate.

Special Considerations: Acute Upper Gastrointestinal Bleeding in the Critically Ill Patient

Stress related mucosal disease in the intensive care setting is a topic of much debate. It is recognized that not all ICU patients have the same risk of developing AUGB. Respiratory failure requiring mechanical ventilation, coagulopathy, hypotension, sepsis, hepatic and renal failure, use of glucocorticoids, traumatic brain injury, burns and enteral feeding have all been implicated as risk factors for mucosal stress disease and the development of AUGB. A study from the Canadian Critical Care Trials Group (57) suggested that the only two risk factors positively correlated with the development of AUGB were the presence of a coagulopathy and mechanical ventilation for more than 48 h. The mortality rate in the subgroup of patients who developed bleeding after admission to the ICU was 50%; however, it was only 9.1% for patients who were admitted for bleeding. Further, it was not clear if the deaths in the former group were due to the bleeding itself or a coexisting condition. The authors argued based on their study that few patients in ICUs should receive routine stress ulcer prophylaxis. However, Reilly and Fennerty (58) reported that 75–100% of critically ill patients demonstrate some evidence of mucosal disease within the first 24 h of ICU admission; that would suggest that acid suppression therapy on admission to the ICU might be

useful. When to use acid suppression therapy as well as which agent to use (H2-receptor antagonists, PPIs, or other agents such as sucralfate) in the critical care setting is still a subject of controversy in the literature. Of note, the Surviving Sepsis Campaign continues to recommend the use of H2-receptor antagonists in patients with severe sepsis, suggesting that their use be weighed against the development of pneumonia in certain patients.(59)

SUMMARY

AUGB remains an important clinical problem. Table 55.3 summarizes the grade of evidence for selected recommendations described in this chapter. The approach to patients with AUGB requires that the clinician understand the potential causes, variations in clinical presentation, principles of resuscitation, and options/indications for specific therapies. Emergency medicine physicians, gastroenterologists, internists, intensivists, surgeons, and nursing staff should work together in an interdisciplinary fashion to successfully manage such patients.

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56 Acute lower GI hemorrhage
Amanda Ayers and Jeffrey L Cohen

A 55-year-old male presents to the emergency room (ER) with bright red blood per rectum. He undergoes resuscitation and has a nasogastric tube (NGT) placed revealing bilious aspirate. A rigid sigmoidoscopy performed in the ER reveals nonbleeding hemorrhoids. A bowel prep is given to the patient and he undergoes a limited colonoscopy on hospital day 1 revealing left-sided diverticulosis but no obvious source of bleeding. He is discharged home on hospital day 4 but returns 1 week later with another massive lower gastrointestinal (GI) bleed. A repeat emergent colonoscopy is limited by moderate amount of colonic blood. A tagged red blood cell (RBC) scan is negative. Angiogram with venous phase reveals right colonic angiodysplasia. The patient undergoes an extended right hemicolectomy.

EPIDEMIOLOGY OF LOWER GASTROINTESTINAL BLEED

Lower GI bleed or hemorrhage (LGIB) is defined as hemorrhage from a source located distal to the Ligament of Treitz. It is a frequent cause of admission to the hospital, accounting for approximately 1% of all emergency hospital admissions.(1) An American College of Gastroenterology survey revealed that LGIB represented 24% of all GI bleeding events.(2) A recent population-based study revealed an incidence of 22 per 100,000.(3) Notably, the annual incidence increased significantly with increasing age. Overall, the annual rate was one-fifth that of acute upper GI bleed (UGIB), which was consistent with findings from other studies. (2–6) This same study also revealed that men were affected more frequently than women.

The causes of LGIB are multiple and varied. The most common etiologies include: diverticulosis, angiodysplasia (including arteriovenous malformations [AVMs], vascular ectasias, and angiomas), neoplasms, ischemic colitis, colitis, hemorrhoids and other anorectal diseases, postpolypectomy hemorrhage, and inflammatory bowel disease. In addition, in patients presenting with bright blood per rectum, as many as one-third are found to have bleeding localized to the small intestine and up to 11% are localized to the upper GI tract.(7) Longstreth's recent review revealed that colonic diverticulosis was the leading cause of lower GI bleeding (41.6% of patients) which is consistent with other studies.(3, 8, 9) Of note, the other commonly quoted etiology, colonic angiodysplasia, accounted for only 6% of LGIBs.

While most patients presenting with LGIB will be older with the concomitant increase in number of medical problems, the outcomes are usually favorable. Mortality rates vary within 4–12% range, although recent studies suggest a decreasing trend. (3, 8, 9) These higher numbers also reflect older studies in which patients frequently underwent emergency surgery. It has been demonstrated that patients developing a LGIB when admitted for a separate process have worse outcomes.(3) In addition, the need for urgent surgery and associated comorbid conditions were identified as risk factors for increased mortality.(8)

While most LGIBs will resolve spontaneously, rebleeding can be a significant problem in many patients, especially in patients with diverticulosis and colonic angiodysplasia, the two most common etiologies. Anthony et al. reviewed 119 patients undergoing ^{99}Tc-RBC scans. This study found the actuarial rate of rebleeding to be 9% at 1 month, 13% at 1 year and 15% at 2 years, which is consistent with other studies.(3, 9)

INITIAL EVALUATION

The most important priority in the initial evaluation of a patient presenting with acute LGIB is resuscitation and stabilization. This should be instituted as soon as possible and may occur prior to and during the initial history and physical examination. Two large-bore intravenous (IV) lines, a Foley catheter, and cardiac monitor to provide continuous hemodynamic monitoring are vital to the determination of the patient's clinical status. With IV access, initial laboratory evaluation should be obtained to include: a complete blood count, coagulation parameters, type and crossmatch, and electrolyte panel. As this initial resuscitation is ongoing, a complete but focused history and physical examination should be performed.

History should be obtained as to the nature, duration, and frequency of bleeding, and any other associated symptoms. A review of the patient's past medical and surgical history, including any prior endoscopic evaluations, will assist in the determination of the necessity for ICU or intermediate level care. Finally, a thorough review of the patient's medication history, paying particular attention to any anticoagulant drugs, aspirin, and nonsteroidal anti-inflammatory drug (NSAID) use, will determine the need for infusion of blood products and other adjuvant medications. A physical exam should be performed, including an abdominal exam, digital rectal exam, and anoscopy.

Once the patient has been stabilized, a NGT should be placed to evaluate for a possible upper source of the bleeding. A bloody aspirate or lavage should prompt the clinician to investigate an upper GI tract source first; however, an aspirate yielding a significant amount of bilious material would suggest the lower GI tract as the more likely source. If the aspirate and lavage are both clear, the etiology may still be from a duodenal source and may require an investigation of the upper GI tract if the source remains elusive. Alternatively, an initial esophagogastroduodenoscopy (EGD) may be performed instead of NGT lavage as both a diagnostic and therapeutic tool. In general, it is prudent to consider proctoscopy as part of the initial ER evaluation. This will provide invaluable

information as to quantity and severity of bleeding, but can also rule out simple anorectal sources such as hemorrhoids, trauma, ulcers, or masses. Identification of a clear anorectal source can prevent the performance of unnecessary diagnostic maneuvers.(10)

Several authors have attempted to identify prognostic factors for the severity of LGIBs. Strate et al. developed and validated a clinical prediction rule utilizing seven factors. The factors included: heart rate $\geq$ 100, systolic blood pressure (SBP) $\leq$ 115 mmHg, syncope, aspirin use, > two comorbidities, rectal bleeding in first 4 h of presentation, and nontender abdominal examination.(11) Low-risk patients had no risk factors, moderate risk patients were defined as those with 1–3 risk factors and high-risk patients as those with > 3. The risk score closely correlated with clinical outcomes such as death, surgery, blood transfusions, and length of stay.(11) Velayos et al. also determined three predictors of severity including: HCT < 35 on admission; abnormal vital signs (hypotension, tachycardia); and gross bleeding on rectal examination.(5) The BLEED classification was published in 1995 to predict hospital outcomes for both lower and upper GI bleeds based on information from the initial emergency department (ED) evaluation. The factors included: ongoing bleeding, SBP < 100 mmHg, elevated INR, erratic mental status, and unstable comorbid disease. These factors were found to be predictive of in-hospital complications, defined as: recurrent GI hemorrhage, surgery required, and hospital mortality. However, this study was based on information from both upper and lower bleeds, which cannot necessarily be directly compared.(4) Finally, Das et al. utilized an artificial neural network to predict outcomes which, while rather accurate, is too laborious at this point for utilization in real-world situations.(12) In essence, each patient must be assessed for severity of bleed and triaged to the appropriate level of care accordingly.

> The case patient was appropriately resuscitated and initial work-up in the ER performed to exclude obvious anorectal sources.

DIAGNOSTIC OPTIONS

There have been previously two widely accepted radiologic methods for imaging lower GI bleeding, formal mesenteric angiography, and nuclear medicine scintigraphy, and more recently a third option, computed tomography (CT) angiogram. In addition, many clinicians have adopted colonoscopy as a first-line diagnostic test and therapeutic option. Each modality has several pros and cons and the applicability depends on individual clinical scenarios. Ideally, bleeding should be localized prior to any operative intervention as a high rate of mortality has been noted, up to 57% in patients undergoing surgical intervention without preoperative localization.(13)

Nuclear Scintigraphy

Nuclear medicine scintigraphy is, in many institutions, the first-line diagnostic option for patients with significant LGIBs. There are two tracers available for utilization: ^{99m}Tc-labeled sulfur colloid (^{99m}Tc-SC) and ^{99m}Tc-labled RBC (^{99m}Tc-RBC). ^{99m}Tc-SC is

useful in that it requires no preparation and thus can be injected immediately. However, it is rapidly cleared from the blood stream and is only useful for localization for a limited period of time. In contrast, the ^{99m}Tc-RBC requires preparation, with the patient's own RBCs being drawn, tagged, and reinjected. The "tagged" cells, however, are not cleared as quickly and this modality enables repeated scanning over a 24–48 h period. Scintigraphy is the most sensitive diagnostic study, and can detect bleeds at a level of 0.1 ml/min or higher.(14, 15) Its shortcoming is the poor rate of localization as it does not provide anatomic correlation, making it impossible to definitively determine a site of bleeding. In addition, it requires a significant amount of preparation time and scanning time, in which a potentially unstable patient is away from an intensive care setting.

The sensitivity and specificity of nuclear scintigraphy is also in question. Studies from the 1970s and 1980s reported sensitivities > 90%, while newer studies have lower rates of sensitivity within the 20–60% range. The later studies also reported lower rates of localization, resulting in incorrect surgical procedures in 42% of cases.(1, 15, 16) The most frequent utilization of the bleeding scan is as a "screening test" for mesenteric angiography: patients with a bleed are sent for scintigraphy and if positive, are sent for angiography.(17) However, a 1997 review revealed that the utilization of bleeding scans as a "screening test" did not reduce the number of negative angiograms.(18)

Mesenteric Angiography

Angiography has now become an accepted standard of care in both the diagnosis and treatment of LGIBs. While its sensitivity for the detection of bleeds is higher than that quoted for nuclear scintigraphy at 0.5–1.0 ml/min, (18) its ability to definitively localize bleeds makes it a far more clinically useful study, especially in patients who may require surgical intervention. Localization rates range 40–85%.(1) Angiography is an invasive study requiring arterial catheterization and the concomitant risks associated with this process: pseudoaneurysm, arterial injury, retroperitoneal bleed, and hematoma, (19) as well as other risks related to contrast infusion. In addition, it requires the availability and, in the off-hours, mobilization, of an on-call interventional team. Often, a positive nuclear scintigraphy scan is required before mesenteric angiography will be attempted in order to reduce the number of negative invasive angiograms. However, in some centers, mesenteric angiography may be the first step for patients with demonstrated active bleeding and hemodynamic instability as both a diagnostic and therapeutic option. Abbas et al. reported that hemodynamic instability was the most useful indicator for a positive angiography.(20)

In patients with negative angiography and continued bleeding, a provocative imaging study can be performed with the coordination of radiologists and surgeons. After cannulation of the mesenteric vessels, vasodilators, anticoagulants, and/or thrombolytics can be infused to "provoke" bleeding in a suspected distribution. While some studies have demonstrated increased rates of localization with these adjuvants (21), there exists significant potential for massive bleeding requiring emergent intervention. Therefore, patients must be adequately prepared with appropriate large-bore access in place, appropriately crossmatched blood

available in addition to communication between all caregivers, particularly interventional radiologists and surgeons.

Helical Computed Tomography Angiography

A newer modality for visualization of LGIB is CT angiography (CTA). This technique is beneficial in terms of its ability to visualize anatomic abnormalities in addition to localization of GI bleeding. A swine model demonstrated that bleeding can be detected at rates below 0.5 ml/min (similar to nuclear scintigraphy).(22) Multiple studies have demonstrated its utility in localizing LGIBs in clinical practice.(23–27)

CTA in our institution is performed initially with noncontrast images through the abdomen and pelvis, followed by injection with 100 ml of Ultravist® 300 mg/ml[AU: Please confirm if the changes are OK.] with the contrast-enhanced scans obtained timed to the portal venous phase in either a 64-slice multidetector or 8-slice multidetector CT. (modified from Kuhle et al.) This allows for both contrast- and noncontrast-enhanced images to be viewed in synchrony, side-by-side, to better assist in the determination of active bleeds. The characteristic findings include hyper attenuating extravasated contrast material visualized within the lumen of the bowel. This protocol is estimated to result in a total of 5.0 rad exposure for each CTA. Other protocols include triphasic scans (25) including a noncontrast phase, arterial weighted phase and delayed phase scans, and a single arterial phase scan with a threshold of 90 Hounsfield Units as diagnostic for extravasated contrast.(23)

CTA's benefits are multiple. First, it can be quickly and easily obtained without any required preparation, even in small institutions. While nuclear medicine and mesenteric angiography's accessibility may be limited at off-hours even in larger institutions, a CT scanner is typically available around the clock. CTA requires nothing more invasive than a large-bore IV, which should already be obtained in the bleeding patient. The rapidity with which it can be obtained is also a major benefit since the patient can be quickly transported from the ED to the CT scanner and does not require multiple hours away from an intensive care setting such as with nuclear scintigraphy. In addition, with the intermittent nature of some sources of bleeding, rapidity to the CT scanner may allow for improved rates of visualization as compared to other modalities which require longer preparation time. Finally, CTA may result in improved localization of bleeding sources, especially for those related to tumors and colonic diverticulosis. This is particularly helpful in bleeds from the small intestine which cannot be well visualized by endoscopy. If a bleed can be seen and localized on CTA, it may allow for more selective mesenteric angiography and therapeutics that are: limited to the SMA versus cannulation of all three mesenteric vessels. The downfall of CTA, similar to mesenteric angiography, is the need for contrast injection, so that patients with either contrast allergy, baseline chronic renal insufficiency, or an acute rise in creatinine (which can be seen in significant blood loss hypovolemia), are not eligible for this type of imaging.

Colonoscopy

The use of endoscopy for both the diagnosis and therapeutic management of upper GI bleeds (UGIB) has long been established.

More recently, many authors have demonstrated the safety and utility of colonoscopy in the setting of LGIBs in an urgent setting.(28–31) Classically, colonoscopy has been thought to have limited utility in those patients who are actively bleeding due to the inability to visualize the mucosa as a result of the quantity of blood, and best reserved for after resolution of bleeding. More recently, authors have published data revealing the safety and possible therapeutic nature of urgent colonoscopy in this setting. (29–32) Zuckerman et al. reviewed 13 studies (1,561 patients) in which colonoscopy was used as the primary modality for evaluation of LGIB with a 1.3% complication rate. This included heart failure, bowel perforation (five patients), exacerbation of bleeding, and septicemia.(15)

The ability to find a bleeding source has ranged 48–90% in these studies.(15) Zuckerman's review of studies from 1982 to 1997 revealed a 68% rate of positive diagnosis in a total of 1,561 patients. Green and Rockey reviewed five studies from 1998 to 2001, with an 88% rate of specific diagnosis in 485 patients.(13) A definitive diagnosis is typically documented in patients with diverticulosis with one of the following stigmata: active bleeding, visible vessel, or adherent clot.(29, 31) Findings of angiodysplasia include: dilated, tortuous vessels and nonulcerated "cherry-red" areas with or without active bleeding.(16) The American Society of Gastroenterology (ASGE) guidelines state that colonoscopy is effective in the diagnosis and treatment of LGIB and is recommended early in the evaluation of severe, acute LGIB.(33)

Other authors have demonstrated, however, that urgent colonoscopy does not change outcomes. Green et al. reviewed two groups of patients—50 who underwent urgent colonoscopy and another 50 who were treated with a "standard care" algorithm including angiography and nuclear scintigraphy. The urgent colonoscopy group had a definitive source of bleed identified more frequently than the standard care group (42% vs. 22%).(30) However, there was no difference in mortality, length of stay, ICU stay, rebleeding rates, transfusion requirements, or need for surgery. Similarly, Angtuaco did not find any significant difference in outcomes for patients undergoing urgent colonoscopy.(34)

The role of colonic cleansing is also somewhat debated—while blood itself may act as a cathartic, many authors still provide a polyethylene glycol purge either orally or via NGT with or without a rectal enema. While it has been argued that purging allows for the best visualization possible, other authors have suggested that it removes stigmata of recent bleeding and pooling of fresh blood, making diagnosis more difficult. Most recent studies have utilized a colonic purge in preparation for endoscopy.(30, 32, 34, 35)

Finally, the timing of colonoscopy is another area in which there is no clear evidence. The definition of "urgent" colonoscopy has varied in the literature from as little as 2–5 h to as much as within 24 h of admission or identification of the LGIB. (15) Endoscopy should take place once the patient has been stabilized and resuscitated, as the need for sedation adds an additional source of possible hemodynamic stability. Regardless of the role for urgent colonoscopy, all patients will require endoscopic assessment of their colon at some point in the evaluation of the LGIB.
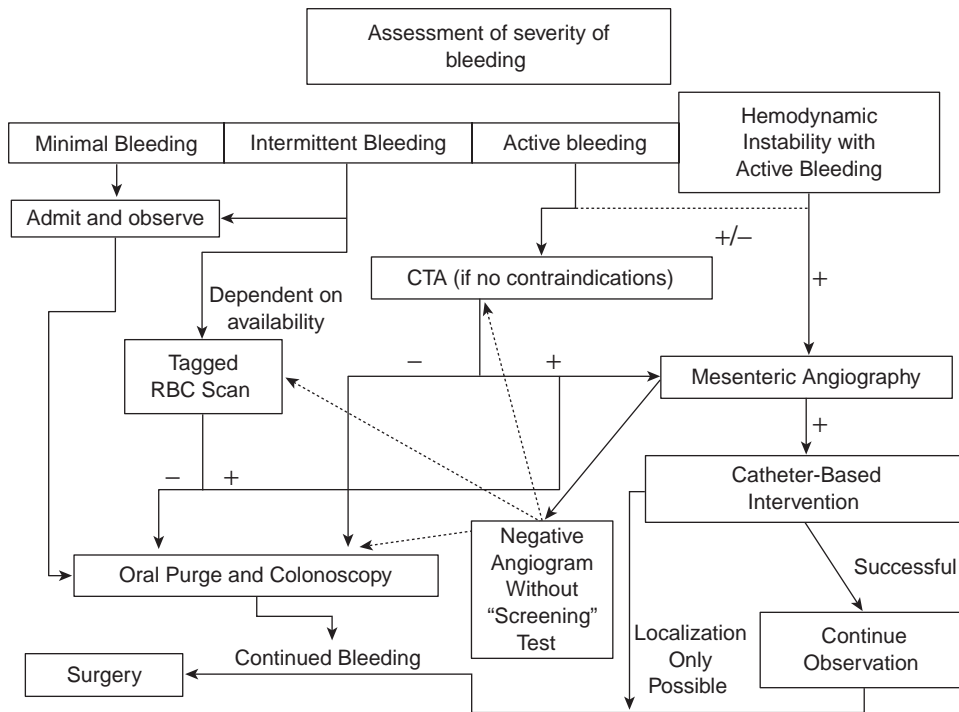
Figure 56.1 Algorithm for management of LGIB.

The case patient was initially resuscitated and the source of bleeding was investigated with "urgent" colonoscopy which did not reveal a definitive diagnosis. As the patient's bleeding ceased, no further investigation was undertaken. After rebleeding required readmission, additional work-up was obtained to localize the source. Repeat colonoscopy was not helpful due to the amount of blood, impairing visualization. He then underwent a tagged RBC scan. Despite the fact that nuclear scintigraphy was negative, his persistent bleeding prompted a mesenteric angiogram. This patient alternatively could have undergone a CTA on admission to evaluate for any evidence of active bleeding, particularly if he was admitted during off-hours and time was required for assembly of the interventional radiology team. Evidence of active bleeding on CTA could direct the radiologist to limited mesenteric vessels, decreasing both the time in the angiography suite as well as dye load. Angiography with venous phase revealed angiodysplasia of the right colon which could not be successfully embolized.

TREATMENT OPTIONS

The treatment of the patient with LGIB is dependent on: hemodynamic stability, rate of bleeding, availability of resources such as mesenteric angiography, and ability to localize the bleed. In most situations, the last common pathway typically is surgical intervention. However, the patient should be brought to surgery in most situations only after the LGIB site has been localized as previous high rates of mortality have been documented in patients undergoing nondirected surgical intervention. A proposed algorithm for the management of LGIB is presented in Figure 56.1.

Endoscopic Therapy

As previously discussed, urgent colonoscopy has been found to be useful in some situations for diagnosis and localization of LGIBs. In addition, there are a number of therapeutic interventions which can be utilized in the management as well.(31, 36–38) Again, the use of bowel preparation is debated in the literature, although most authors feel it to be beneficial and reducing the risks of perforation due to lack of visualization.

Green and Rockey's review reported a rate of 10–15% of endoscopic intervention when urgent colonoscopy was utilized. (13) Typical interventions include injection with epinephrine or saline, and electrocoagulation. Other authors have reported the use of newer and less utilized techniques for hemostasis, such as hemoclips and band ligation of diverticular hemorrhages.(13, 38, 39) While diverticulosis and angiodysplasia are most amenable to endoscopic therapy, (1) the diagnosis of other lesions, particularly neoplasms and ischemia also assist in appropriate management.

Jensen et al. reported 10 patients with definite stigmata of diverticular bleeds treated by endoscopic therapy, with no early or late rebleeding.(31) Numerous other small series and case reports have suggested that early therapy with coagulation and epinephrine injection is effective.(29–31, 37, 40) However, other authors have demonstrated higher rates of rebleeding. In a prospective trial of urgent colonoscopy for acute LGIB by Green et al. 34% of 50 patients underwent endoscopic therapy, with a 22% rate of early rebleeding and a 16% rate of late rebleeding. This was no different than those treated by standard care algorithm (nuclear scintigraphy and mesenteric angiography).(30) Bloomfeld et al. performed a retrospective review and identified 13 patients who underwent endoscopic therapy. Of these, 38% experienced early rebleeding (within 30 days) and 23% developed late rebleeding. (29) Endoscopic therapy may be helpful in the acutely bleeding

patient, however, it is still unclear that it is the best modality for therapy.

Percutaneous Endovascular Techniques

Mesenteric angiography as described previously has become an invaluable tool in the work-up of LGIBs. In addition to localization, it has been recognized that therapeutic intervention is also possible, sparing patients from the need for surgical intervention. Patients must demonstrate bleeding at a fast enough rate to be detected on angiography and this is its biggest drawback. The two main modalities for therapy via angiography are vasopressin infusion and embolization.

Vasopressin infusion is rarely utilized in our institution due to its high risks and the relatively good outcomes with transcatheter embolization. When performed, the site of bleeding is localized, and a catheter is positioned in the area supplying the site of bleeding. The infusion is initiated at 0.2 units/min and can be increased to 0.4 units/min if bleeding continues. A repeat angiography is performed in 20–30 minutes to determine if bleeding has ceased. The catheter is then left in place and the patient is transferred to an ICU for close monitoring. The infusion is continued for 6–12 h at the same rate, then decreased by half, and finally tapered off during the following 12–24 h. As mentioned, vasopressin infusion has significant risks due to its potent vasoconstrictive properties, especially with respect to myocardial and peripheral ischemia, significant hypertension, hyponatremia, and arrhythmias, and is therefore contraindicated in patients with a history of coronary artery disease and peripheral vascular disease. Frequently, it is administered in conjunction with a nitroglycerin infusion in order to limit its systemic adverse effects. In addition, other adverse outcomes such as mesenteric thrombosis, intestinal infarction, and death have been reported.(1) Finally, rates of rebleeding of up to 50% have been reported.(41)

Currently, the standard of care for angiographically localized bleeds is transcatheter superselective embolization. Embolization, initially reported in 1975 with good results, was found in the 1980s to have significant rates of bowel ischemia (up to 20% (42, 43)) leading many to abandon this modality. However, more recent technological advances, including the introduction of microcatheters, better torque devices, high resolution digital angiography, and newer embolization materials have led to increased utilization.(44) The use of superselective embolization, made possible by these technical advances, has led to reduced rates of bowel ischemia to acceptable levels of < 10%.(41, 43, 45, 46) A large study from our institution confirmed earlier data with a rate of 7% of colonic ischemia.(41, 46) It should be noted that bleeding which occurs at a site of surgical anastomosis should not be treated with embolization and should be referred for surgical intervention.

Once bleeding has been identified, several different particles are available for microembolization including: polyvinyl alcohol particles, microcoils, Gelfoam®, and glue, either singly or together. In order to decrease rates of ischemia, the most distal location possible is embolized. If bleeding can only be controlled by a proximal embolization, the patient should instead be considered for surgical intervention, and direct communication must exist between surgeons and interventional radiologists in these scenarios.

Rates of rebleeding following embolization have been reported at the rate of 0–30%.(44) A recent long-term follow-up study of 71 patients was performed at our institution with a successful immediate intervention (97% rate of hemostasis) with a 16% rate of early rebleeding, one-third of which were successfully reembolized in the short-term. A long-term follow-up of 52 patients revealed eight readmissions for bleeding (15.4% late rebleeding). (46) These are slightly lower when compared to rates of rebleeding following colonoscopy (20–40%) previously mentioned.

Operative Intervention

As previously discussed, many patients presenting with LGIB are older in age with multiple medical comorbidities. In combination with possible hemodynamic instability related to blood loss, these patients are typically high-risk candidates for surgical intervention. In the 1970s, the only modality for therapy was surgical intervention for bleeding which did not cease spontaneously. Initially, blind segmental colectomy of the left colon was the procedure of choice, prior to the recognition of angiodysplasia and right-sided diverticuli as common sources. This led to a 12% mortality rate and 30–63% rebleeding rate.(1, 44) Other studies quoted mortality rate as high as 20–40% and rebleeding rate as high as 57%.(47) These poor results led surgeons to elect to perform total colectomies in the 1970s and 1980s for LGIBs.(1) The mortality rates for emergency subtotal colectomy ranged 9.4–40%.(14, 44) However, the rate of rebleeding was significantly reduced.(44) The advent of localization studies, such as nuclear scintigraphy and localization angiography, allowed for more limited resections, but mortality rates were still as high as 10%.(44)

Despite the number of possible alternate therapeutic interventions, surgical resection remains the final common pathway for treatment of LGIBs and is required in 10–25% of patients.(1, 14) Ideally, bleeds should be localized prior to surgery either angiographically, by CTA, or at times by nuclear scintigraphy. Many surgeons remain uncomfortable doing a limited resection based on nuclear scintigraphy alone, as the localization is nonspecific. Localization will allow for limited resection of the affected portion of the colon and/or small bowel.

If localization is not possible prior to surgical intervention, total colectomy is treatment of choice.(1, 48, 49) However, there are a number of manipulations that can be performed to assist in limitation of resection. Patients should be placed in the modified lithotomy position in order to facilitate intraoperative endoscopy and anastomosis if the patient's condition allows. First, exploration of the abdomen must be completed to search for tumors or other obvious sources of bleeding, particularly in the small intestine. Intraoperative endoscopy can be performed and several authors have described techniques of lavage via cecostomy tube. (50, 51) Push enteroscopy and passage of the endoscope orally with intraoperative manipulation of the small intestine can also be performed in order to visualize the entire length of the small bowel.(52) If upper and lower endoscopies have been negative and a site has been confirmed within the small intestine (i.e., by wireless capsule endoscopy), a limited or even laparoscopic approach may be utilized to complete push enterosocopy. If the source can be localized to the colon and a rectal source has been ruled out, a subtotal colectomy can be performed with ileorectal anastomosis

or ileostomy, depending on the patients hemodynamic stability and comorbidities.(1, 14, 48, 49)

Indications for surgical intervention are varied depending on the availability of angiographic and endoscopic therapy. Rebleeding within 1 week of initial cessation, continued bleeding for 72 h, > 4 unit transfusion requirement within a 24-h period have all been suggested as absolute indications for surgical intervention.(14) It cannot be emphasized enough, however, that if at all possible, localization should be obtained prior to surgical intervention. As long as the patient can be stabilized and not in jeopardy resulting from hemodynamic instability, further diagnostic maneuvers are usually the most prudent approach.

This patient may have been effectively treated with superselective embolization. However, his relatively young age and lack of comorbidities as well as the definitive localization to the right colon by angiography make him a "good" surgical candidate. A summary of evidence-based recommendations is provided in Table 56.1.

SPECIAL CONSIDERATIONS

Anticoagulation

The increased number of patients on antiplatelet therapy and full anticoagulation makes this a frequent confounding variable in the work-up of patient's with LGIBs. Obviously, in the patient with evidence of active bleeding and hemodynamic instability on anticoagulant therapy, one of the initial priorities is to correct the coagulopathy. This becomes more difficult in the patients requiring anticoagulation, such as those with mechanical heart valves and recent placement of coronary drug-eluting stents. Patients requiring anticoagulation for deep vein thrombosis (DVT) and pulmonary embolism (PE) may be better served with placement of an inferior vena cava (IVC) filter. Frequently, discussion must be held between specialties and with the patient to determine risk benefit ratio of continued anticoagulation in patients at high risk for recurrent LGIB. Occasionally, these patients may require surgical or endoscopic intervention to remove a bleeding source in order to continue anticoagulant or antiplatelet therapy.

Elderly

As previously described, the incidence of LGIB rises dramatically with age, as does the most common causes of bleeding: diverticulosis, and angiodysplasia. These patients are even more difficult to assess and manage due to the number of comorbidities that increase with age. Elderly patients are more likely to have cardiac disease, vascular disease, renal disease, be on anticoagulants or antiplatelet therapy, all of which complicate their work-up and place them in the higher risk category. In addition, many of these patients will be maintained on beta-blocker therapy for management of cardiac conditions, making initial assessment of their hemodynamic stability more difficult, as it masks tachycardia. Therefore, careful evaluation of elderly patients presenting with LGIBs must be completed with a low threshold to place these patients in ICU settings for observation.(53)

Table 56.1 Evidence-Based Recommendations for Management of LGIB.

Recommendation	Level of Evidence
CTA is a useful adjunct for localization of LGIBs (23–27, 58–62)	1C
Selective embolization of LGIBs is a safe, effective method of treatment (41, 43, 46, 63, 64)	1B
Localization of bleeding should be sought prior to operative intervention (8, 48, 49)	2C
Total abdominal colectomy with end ileostomy should be performed in unstable patients requiring operative intervention prior to localization (48, 49)	1B

INFLAMMATORY BOWEL DISEASE

Crohn's disease and ulcerative colitis are uncommon etiologies for massive LGIBs.(1, 54) In six of eight studies between 1962 and 1997, patients with massive LGIB were more likely to have Crohn's disease than ulcerative colitis. Endoscopy is frequently utilized for localization.(54) In patients with Crohn's who require surgical intervention, localization is paramount prior to resection to limit the amount of resection.

Postpolypectomy Bleeding

While postpolypectomy bleeding is an infrequent cause of LGIB (2–6%) (33), it is one of the most common complications of polypectomy. It can occur up to 1–2 weeks later after sloughing of the eschar (13) and may be increased by the use of NSAIDs. (13) While many patients will cease bleeding spontaneously, some will require intervention which is typically managed endoscopically. Resnaring, coagulation, epinephrine injection, hemoclips, and loop or band ligation have all been attempted with success.(1, 13)

Radiation Colitis

The utilization of pelvic radiation for therapy of prostate and other pelvic malignancies has made radiation proctitis a more frequent problem. Radiation induces damage to the rectal and distal colonic mucosa, resulting in formation of vascular malformations. Multiple modalities have been employed for nonsurgical therapy, including topical therapies such as steroid enemas, 5-aminosalicylic acid, and sucralfate, with limited success. Endoscopic therapies have been found to be useful, specifically with the use of argon or laser coagulation.(13) Installation of formalin into the rectum has also been shown to be effective to control bleeding. (55–57) Surgical intervention may be required if these therapies fail or for other complications such as stricture or fistula formation in the form of diverting colostomy.

Infectious Colitis

Colitis related to infectious agents such as *Salmonella typhi*, *Eschericia coli* O157:H7, *Campylobacter jejuni*, *Yersinia enterocolitica*, *Clostridium difficile* (*C. diff*) and *Cytomegalovirus* (*CMV*) can result in LGIBs. Frequently, these patients will present with bloody diarrhea and abdominal pain as part of their

symptomatology. With the increasing numbers of recognized *C. diff* colitis, the clinician should have a high suspicion for this disease in patients with LGIB, abdominal tenderness, leukocytosis, and history of recent antibiotic usage or institutionalization. In patients with a history of immunosupression, particularly posttransplant recipients and those with HIV, *CMV* should be high on the differential. Diagnosis is typically obtained with endoscopy, either by characteristic appearance or biopsy to aid in the guidance of medical therapy.(13)

Ischemic Colitis

Ischemia has been recognized as a more frequent etiology in recent years. While rectal bleeding may be an initial presenting finding, it is not typically a cause of hemodynamic instability. The classic scenario is a patient who presents with abdominal pain, followed by bloody diarrhea and frequent ccomplaining of abdominal discomfort as a significant symptom. Frequently, these patients will demonstrate leukocytosis. Resuscitation is key in these patients, with the addition of antibiotics. A CT scan may be beneficial to evaluate for bowel wall thickening or inflammatory changes. A certain subset of patients will present with significant ischemia that may require surgery, however, this is more commonly due to transmural necrosis and signs of sepsis rather than bleeding. Other patients can be managed expectantly with antibiotics, bowel rest, and possible endoscopic evaluation. Ischemia should also be considered high in the differential for patients with certain vasculitides such as Wegener's, polyarteritis nodosa, and rheumatoid arthritis.

Neoplasm

Most frequently, colonic neoplasms will present with occult bleeding, not acute hemorrhage. The classic picture is a patient who presents with symptomatic anemia. However, in elderly populations, 10–15% of severe LGIB is related to neoplasms.(1) Longstreth found that 9% of LGIBs were due to neoplasm.(3) Once discovered, the management depends on location, pathology, amenability to endoscopic removal, and overall health status of the patient. Some patients, even with evidence of metastatic disease, may require local resection for management of persistent low-volume bleeding, to decrease admissions for symptomatic anemia.

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57 Perirectal and perineal sepsis
Frederick D Cason and Yazan Duwayri

SECTION I: ACUTE PERIANAL, PERIRECTAL AND PERINEAL SEPSIS

INTRODUCTION

Infections in the perianal and perineal regions are potentially aggressive and are truly surgical because they involve multiple organisms, endogenous to the local anatomic area, which may cause tissue necrosis and significant morbidity, and even death. The requirement for surgical drainage or debridement and source control are almost universal and a large array of host defenses are challenged over the course of the development and resolution of these important infections. Both are frequently not recognized to be serious when initially seen by non-surgeons. The risk factors for these infections range from the natural wear and tear of defecation and urination to trauma and immune-compromising conditions, such as diabetes, inflammatory bowel disease, steroid use, and old age. Both perianal sepsis and perineal soft tissue infection are addressed together in this chapter because of their shared anatomic proximity, therapeutic management, bacteriology, cytokine milieu, and infrequency in which they are addressed in surgical education. Importantly, however, they each have some unique features of presentation, patients affected, and management that deserve that they each be discussed in separate sections of this chapter.

Case example

A 45-year-old obese, brittle, insulin-dependent diabetic woman presents to the Emergency Department (ED) with a 4-day history of a progressive, painful, tender perianal mass and exacerbated pain with attempted defecation. She reports the problem to have started as a pimple in the left perianal area. She now describes tenesmus, constipation, fever, loss of appetite, and high readings on her finger stick blood sugar testing. Her temperature is 102.4°F and blood pressure (BP) is 98/56 mm Hg. Perianal examination reveals a large, tender, left-sided ischiorectal mass. Attempted anorectal examination initiates extreme discomfort that the patient is unable to tolerate. An area of erythema extends for several centimeters around the fluctuant mass. Vaginal and abdominal examinations are normal. Blood sugar is 460 mg/dl and the white blood cell count (WBC) is 30,000/mm³. She is hydrated with 2 L of crystalloid solution and given broad-spectrum antibiotics (piperacillin and tazobactam). A pelvic computed tomography (CT) scan is obtained demonstrating a large, left ischiorectal abscess with extension above the pelvic levator musculature. She is then taken to the Operating Room (OR) for examination under anesthesia, anoscopy, and incision and drainage of the abscess. A Foley catheter is inserted into the bladder, and 575 ml of dark-colored urine was drained.

During anorectal examination, a fistula, leaking purulent drainage is identified at the dentate line adjacent to the abscess. Incision and drainage is accomplished and a seton is placed around the internal and external sphincters. The abscess cavity is irrigated with saline and packed very lightly with roll gauze.

She is admitted to the surgical ward and initially improves; however, over the next 8–12 h, she demonstrates continuous fever of 101–102.8°F and pain in the perineum. Re-examination reveals crepitus in the left labia majora and two small, dark bullae in the skin adjacent to the area of previous abscess drainage. An X-ray is obtained showing air in the tissues of the labia and portions of the upper thigh. She is returned to the OR where the areas of crepitus and bullae are widely excised. Tissue undermining, necrosis, and edema are identified up to the left groin. All necrotic soft tissues are debrided. Postoperatively, short-interval dosing of antibiotics is ordered, and the wounds are inspected in the Hubbard tank every 4–6 h over the next 12–18 h. Defervescence occurs over the next 12–24 h; no additional necrosis or crepitus is noted, and the patient markedly improves. IV (intravenous) antibiotics are continued for 7 days and Hubbard tanking and sitz baths are administered during this time. Tight glycemic control is achieved. The patient is discharged on the 7th hospital day with plans to receive wound care at home and a regular follow-up with the clinic.

This case scenario emphasizes several important issues in the evaluation and management of perirectal sepsis, which will be addressed in this chapter.

1. Etiology, anatomy and classification of perianal and perirectal abscess.
2. Clinical presentation.
3. Bacteriology of perianal and perirectal sepsis.
4. Imaging for perirectal sepsis.
5. Evidence-based treatment options.
6. Outcome of treatment and treatment-related complications.
7. Perianal abscess management in children.
8. Other considerations.

Anterior view

Supralevator abscess

Deep postanal-space abscess

Perianal abscess

Intersphincteric abscess

Ischiorectal abscess

Posterior view

"Horseshoe" shaped perianal abscess
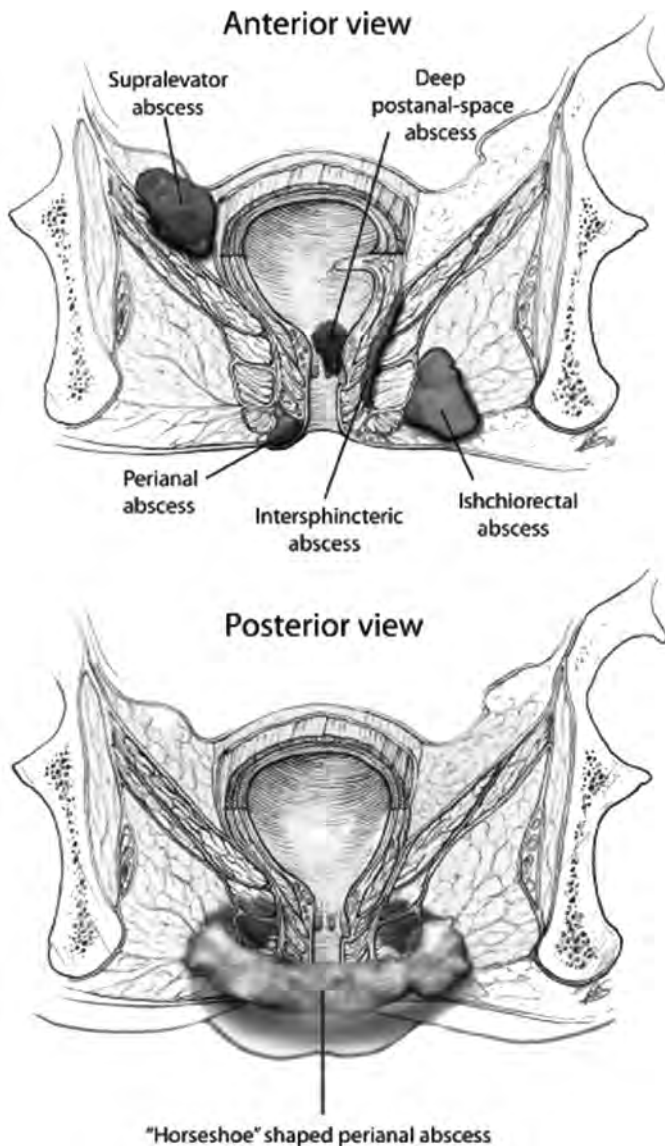
Figure 57.1 Clinical presentations at the perineum.

ETIOLOGY, ANATOMY AND CLASSIFICATION

Who gets perirectal sepsis?

Perianal and perirectal sepsis, abscess, and fistula occur in all age groups. The peak incidence is in the third and fourth decades of life. (1) There is no clear indication as to why these age groups are more vulnerable than the other population. Other factors may include diet, number of bowel movements, and hygiene of individuals at these ages. Data are insufficient to make meaningful epidemiologic comparisons with other parts of the world where diet and dietary habits may be quite different. There is no racial predilection identifiable in American patients. Men are affected more frequently than women with a male-to-female incidence ratio of 2:1 to 3:1.(2, 3)

What causes suppurative disease in the perianal and perineal region?

A. Cryptoglandular infection
The majority of anorectal suppurative disease results from obstruction and infection of the ducts of mucous-secreting anal glands (cryptoglandular infection) found in the intersphincteric plane. Their ducts traverse the internal sphincter and empty into the anal crypts at the level of the dentate line. Infection of an anal gland results in the formation of an abscess that enlarges and spreads along one of several planes in the perianal and perirectal spaces, which are unable to resist the spread of infection and leads to various clinical presentations at the perineum (Figure 57.1).

B. Pilonidal Disease
Pilonidal disease refers to a hair-containing sinus, cyst, or abscess occurring mainly in the sacrococcygeal region. The etiology is unknown, but it is speculated that the intergluteal cleft draws hair into the midline pits when a patients sits. An inflammatory process surrounding these ingrown hairs results in a cyst or a sinus tract. If this in turn becomes infected, the patient will present with an acute abscess in the sacrococcygeal region.

C. Hidradenitis suppurativa
Hidradenitis suppurativa is an infection of the cutaneous apocrine sweat glands. The infection may mimic and is often confused with cryptoglandular abscesses. Chronically infected glands may rupture and form subcutaneous sinus tracts. This infection is differentiated from cryptoglandular perianal septic disease by the lack of communication to the anal canal, due to the absence of apocrine glands there, and by microbiologic criteria as will be detailed below.

D. Immunocompromised states
Acquired Immunodeficiency Syndrome (AIDS) is a known factor causing predisposition to suppurative anorectal disease. Other conditions causing an immune-compromised state, which renders victims susceptible to anorectal sepsis, include chronic granulomatous disease (CGD), autoimmune bullous dermatoses, and leukemia. CGD is an inherited disorder of phagocytic cells that are unable to produce bactericidal superoxide anions leading to recurrent life-threatening bacterial and fungal infections. These patients have been reported to develop anorectal sepsis. Patients with autoimmune bullous dermatoses have a blistering illness, affecting primarily the oral mucous membranes but occasionally involves the anorectum resulting in anorectal sepsis.

E. Miscellaneous
Crohn's disease, cancer radiation proctitis, and trauma can also be responsible for the development of perianal and perirectal abscess. The named anatomic spaces may be disrupted or violated, and the associated anatomy of infections may be unusual.

What are the planes into which cryptoglandular suppurative disease can spread?

The intersphincteric space is located between the internal and external anal sphincters and is where the anal glands are located. The perianal space immediately surrounds the anus and is continuous with the intersphincteric space superiorly. The ischiorectal space is located lateral and posterior to the anus and is bounded medially by the external sphincter, laterally by the ischium, and superiorly by the levator ani. The ischiorectal space is continuous with the perianal space medially. The deep postanal space is located where

both ischiorectal spaces join posteriorly, inferior to the levator ani muscles. The supralevator spaces lie superior to the levator ani on either side of the rectum and also communicate posteriorly.

The anatomy of the above-mentioned spaces corresponds to the different anatomical locations of cryptoglandular abscesses. A perianal abscess is the most common manifestation (43%) and appears as a painful swelling at the anal verge. An ischiorectal abscess is the second most common (23%) and results from spread of infection through the external sphincter, inferior to the levator ani. Intersphincteric abscesses occur in the intersphincteric space (21%) and are notoriously difficult to diagnose, often requiring an examination under anesthesia. Supralevator abscesses are uncommon (7%) and may result from extension of an intersphincteric or ischiorectal abscess upward.

CLINICAL PRESENTATION OF ANORECTAL SEPSIS

What are the common symptoms of perianal sepsis?
Perirectal and perianal abscesses are generally accompanied by intense anal pain. A palpable mass can be identified externally if the abscess is perianal or ischiorectal. Digital rectal examination might not be tolerated, and therefore, anoscopy under anesthesia might be necessary for the diagnosis of intersphincteric or postanal abscesses. Patients frequently report the inability to sit, the sensation of a full rectum, and the urge to defecate without success (tenesmus). Examination is poorly tolerated and the surgeon should not persist at attempting to examine such a patient without the benefit of general anesthesia. Fever and signs of prostration can occur with neglected cases. Occasionally, the abscess spontaneously ruptures and drains, as a result reduces the pain and pressure. Superficial perianal abscesses can be incised and drained using local anesthesia, topical anesthetics (ethylene chloride spray), and conscious sedation under appropriate monitoring. Complications and inadequate treatment are likely without a relaxed patient, good light, and appropriate instrumentation.

Fistula-in-ano, however, is generally painless. It can be associated with the drainage of pus, blood or mucus. Patients sometimes report only stool or bloody discharge staining of their underwear.

Does the fistula-in-ano occur before or after drainage of the perirectal abscess?
Overwhelmingly, fistula-in-ano is caused by a previous perirectal abscess. An internal fistulous opening is identified in almost 35% of cases of perianal and perirectal abscesses.. The external opening is usually created at the site of incision and drainage. The overall prevalence of fistula-in-ano is 8.6 cases per 100,000 population. Other fistulae develop secondary to trauma, Crohn's disease, carcinoma, radiation therapy, local tuberculosis, actinomycosis, and Chlamydial infections.

BACTERIOLOGY

What is the significance of culture results in perianal septic states?
As mentioned above, anorectal sepsis on the buttock may arise from local cutaneous infection due to colonization of obliterated apocrine glands or may also start in an abnormal or obstructed anal gland, leading to intersphincteric sepsis that extends to the perianal and ischiorectal space. The microbial etiology has been found to correlate with the pathogenesis of this condition, that is, the presence or absence or anal fistulae. Colonization by gut-derived organisms as opposed to skin-derived organisms is more likely to be associated with perianal fistula. The presence of skin-derived organisms, however, has been found to be significantly higher in patients without fistula.(4, 5)

What are the most common organisms identified?
In general, mixed aerobic and anaerobic organisms are isolated in 7–80% of patients; aerobic organisms in 10–12.5%; and anaerobic organisms in 5–7.5%. The most common bacterial isolates are *Bacteroides fragilis*, *Peptostreptococcu*s spp., *Prevotella* spp., *Staphylococcus aureus*, *Streptococcus* spp., and *Escherichia coli*.(6) More recently, however, a larger percentage of these abscesses (23%) contained methicillin-resistant S. aureus. These abscesses are also less likely to be of cryptoglandular origin and manifest greater inflammatory response. Identifying the bacterial etiology of perianal sepsis not only is important in the tailoring antibiotic treatment in patients that fail to respond to incision and drainage alone but also in deciding whether these patients should be submitted to further anorectal examination to rule out a fistula as an underlying factor.(7)

IMAGING
The role of imaging in the preoperative treatment of patients with acute perianal sepsis continues to evolve. In general, CT, magnetic resonance imaging (MRI), and endorectal ultrasound can identify the abscesses, their topographical location, and the internal opening of the fistulas if present.

What are the different imaging modalities used in the patients with suppurative infections in the perianal and perirectal areas?
CT scans with oral and/or rectal and IV contrast can be utilized as part of the initial evaluation to diagnose abscesses in patients with unclear presentations, such as perianal pain, fever, tenesmus, and non-palpable mass. CT scan, however, is not a substitute for examination under anesthesia in a patient with a high index of suspicion of deep perirectal abscess. The CT scan can be especially valuable in the cases of deep perirectal and ischiorectal abscesses and extensive, deep postanal space infection. These infections can spread to an area distant from the anal verge while very little is detected by clinical examination alone. CT scans, therefore, can guide treatment of supralevator and ischiorectal abscesses.

Endoanal and endorectal ultrasonography (EUS) is also helpful in the diagnosis of intersphincteric, submucosal, and supralevator perirectal purulent collections. This is particularly valuable intraoperatively to guide treatment in patients with recurrent abscesses in whom anoscopy may be misleading due to scarring.(8) EUS can help in preoperative identification of simple and complex perianal fistulas.

MRI offers high-resolution imaging that defines the anatomy of perirectal sepsis in relation to the internal and external anal sphincters as well as to the levator plane. MRI also is valuable in identifying fistulous tracts, whether intersphincteric, transsphincteric or suprasphincteric in location.

Is imaging needed in all cases?

In most cases of perianal sepsis, however, the above-mentioned imaging modalities are not required. This is particularly true in the most commonly encountered presentation of perianal abscess formation without prior history. On the other hand, specialized imaging is of utmost importance in patients with suspected complex fistulae or recurrent disease. An accurate method of preoperative imaging to delineate primary and secondary tracts and collections as well as the site of the internal opening of the fistula may prevent further recurrence and avoid iatrogenic sphincter injury.(9)

TREATMENT

A perianal abscess should be treated in a timely fashion by incision and drainage. Treatment goals should include the drainage of pus, debridement of obvious necrotic tissue, and the prevention of premature closure of the incision. Drainage should be done even if fluctuance cannot be manifested, as antibiotics alone would not resolve the deep tissue infection with necrosis and cellulitis. The latter can be accomplished by the excision of an ellipse of skin, insertion of a drainage catheter, or placement of a seton. (10) As indicated above, although the simple superficial perianal abscess can be treated in the emergency room, more complex infections require examination under anesthesia.

With the exception of high-risk patients such as those with diabetes, immunosuppression, or significant cellulitis, antibiotics are generally not indicated. Prophylactic perioperative antibiotics, however, are indicated in patients with prosthetic devices and in whom cardiac conditions warrant endocarditis prophylaxis.

Does the anatomic location of the cryptoglandular perianal abscess affect the technique of surgical treatment?

Perianal abscess

Most perianal abscesses can be drained under local anesthesia in the office, clinic, or emergency room. Larger, more complicated abscesses may require drainage in the OR. A cruciate skin incision is made over the prominent part of the abscess, close to the anal margin, pus is evacuated, and the wound is packed with iodoform, dry or antibiotic-soaked gauze. The packing is removed the next day during a sitz bath that is performed twice daily. Identification of the internal opening of the fistula will require an anoscopy, which can be difficult due to extreme patient discomfort. This is, therefore, performed as an outpatient, 2–4 weeks after the drainage, to rule out a fistula as a possible cause for future recurrence. If a fistula is found, it is treated by fistulotomy. Some authors have argued for fistulotomy at the time of initial drainage. This however does not significantly reduce the incidence of fistula when compared to incision and drainage alone done initially.

Ischiorectal abscesses

An ischiorectal abscess may present as diffuse swelling and tenderness in the ischiorectal fossa that may involve one or both sides, forming a 'horseshoe' abscess. Simple ischiorectal abscesses are drained through an incision in the overlying skin. The incision should be made as close to the anal verge as possible in order to keep the length of the fistula, if present, short. Anoscopy can also be performed simultaneously or delayed for 2–4 weeks. Fistulotomy is performed if an internal opening is found.(11)

Horseshoe abscesses and deep postanal abscesses:

The deep postanal space is deep to the external anal sphincter muscles and inferior to the levator. Abscesses of this space may extend bilaterally forming a horseshoe abscess. Symptoms include severe rectal pain, tenesmus, and fever. A horseshoe abscess may also have an ischiorectal abscess as its only external manifestation. Draining the postanal space involves unroofing of the posterior midline anal structures by dividing the internal sphincter. Counter incisions in the ischiorectal space are performed if a horseshoe abscess is encountered. A posterior midline internal opening is almost always identified and unroofing the posterior midline structure provides therapeutic fistulotomy.(12)

Intersphincteric abscess

Intersphincteric abscesses produce few perianal signs of infection. The pain is intrarectal and so intense that it usually precludes a digital rectal examination. The diagnosis is made based upon a high index of suspicion and usually requires an examination under anesthesia. An intersphincteric abscess is drained internally through a limited internal sphincterotomy. Drainage of this abscess externally through the ischiorectal skin-covered area is avoided since it creates a fistula.

Supralevator abscess

This type of abscess is uncommon and is frequently associated with obesity, diabetes, or immunocompromised states. Because of its proximity to the peritoneal cavity, supralevator abscesses can mimic other lower abdominal pathologies and produce fever and leukocytosis. CT scans are therefore valuable in the diagnosis of this condition.

In the treatment of supralevator abscesses, identification of an internal opening of the fistula-in-ano is essential to establish the origin of the septic process. Abscesses forming as an extension of an intersphincteric abscess should be drained through the rectum. On the other hand, if this abscess is an upward extension of an ischiorectal abscess, it should be externally drained. It can be approached as any pelvic abscess by extraperitoneal groin incision or by laparotomy if necessary. Drainage of this type of abscess through the rectum may result in an extrasphincteric fistula.

How is a pilonidal abscess treated?

An acute abscess should be incised and drained as soon as the diagnosis is made. Because these abscesses are usually very superficial, this procedure can often be performed in the office, clinic, or emergency room. Because midline wounds in this region heal poorly, some surgeons recommend using an incision lateral to the intergluteal cleft.

A number of procedures have been proposed to treat a chronic pilonidal sinus, which is beyond the context of this text on acute care surgery. The simplest method involves excision of the cyst wall and allowing the wound to heal by secondary intention. The wound must then be kept clean and free of hair until healing is complete.

What is the treatment of perineal and perianal abscesses resulting from hidradenitis suppuritiva?

Treatment involves incision and drainage of acute abscesses. Unroofing of all chronically inflamed fistulae and debridement of

granulation tissue may be needed in recurrent cases. Antibiotics are indicated when there is significant cellulitis or evidence of systemic infection. Recurrent infection and chronic draining sinuses are best managed by excision of the involved skin containing these apocrine glands followed by primary closure or skin grafting.

Outcome of treatment and treatment-related complications

Most acutely treated cases end in resolution. The incidence of abscess recurrence is 10%. Fistula formation occurs in 37%. This occurs more commonly in females (50% vs. 31% in males), anterior abscesses (88% vs. 33% for posterior abscesses), and in abscesses harboring enteric-derived organisms.(13)

Necrotizing soft tissue infection of perineum can occur in diabetics and other immune-compromised states or when initial surgical management is delayed or inadequate.(14, 15) This is also referred to as Fourniere's gangrene. Physical examination reveals extensive skin crepitus or bullae that are evidence of necrosis. Patients often have fever and leukocytosis. This disease can progress to fatal septic shock if left untreated. Treatment involves wide repetitive surgical débridement of all necrotic tissue, broad-spectrum antibiotics, and nutritional supplementation. Stool diversion might be necessary for effective wound care (see the second section of this chapter for more details on the diagnosis and management of necrotizing perineal infection).

OTHER CONSIDERATIONS

When should inflammatory bowel disease be suspected?

Crohn's disease should be suspected if there are numerous complex fistulous tracts associated with edematous skin tags, or if there is inflammation of the rectal mucosa. The treating surgeon should ask about associated abdominal symptoms.

What is the treatment of perianal sepsis associated with Crohn's disease?

Purulent infections should be drained as in all other cases. Further therapy, in cases in which a fistula is identified as the underlying factor, currently combines different types of surgical therapy by means of fistulotomy, fibrin glue injection, or advancement flaps. The role of infliximab in the surgical management of perianal Crohn's disease is still being evaluated.(16–18) More detailed discussion of fistulizing Crohn's disease is beyond the scope of this chapter.

Should a different strategy be employed in the management of infants with perianal abscesses?

Cryptoglandular abscesses are a common entity in infants. Management of this condition is still controversial in this age group. It has been found that simple incision and drainage in children under 12 months of age would result in a 35–40% incidence of fistula-in-ano.(19–21) Systemic antibiotics and local hygiene measures have been found effective in infants. Furthermore, nonoperative management has been found to decrease the incidence of subsequent fistula-in-ano formation.

What is the management of perianal sepsis in immunocompromised patients?

Patients with hematologic malignancies, those on steroids, patients with neutropenia secondary to chemotherapy, or individuals with AIDS are susceptible to developing anorectal sepsis. The incidence of perianal abscesses has been reported to be up to 34% in patients with AIDS.(22) We are uncertain whether this is due to the pathophysiology of infection as a result of the reduction in T-lymphocytes, a direct effect of the HIV, HPV or other local viruses, related to the trauma of anal sexual intercourse in some male patients, a combination, or other factors. Perianal sepsis can be a cause of major morbidity and mortality in these individuals. The morbidity can range from necrotizing soft tissue infections to metastatic abscesses.(23) Correlations of the severity of presentation and the complication rate have been made with CD4 or neutrophil counts. The diagnosis of perianal infections in immunocompromised individuals can represent a challenge since these patients may not manifest the cardinal signs of inflammation. A high index of suspicion should, therefore, be maintained if perianal symptoms arise, and an examination under anesthesia should not be delayed. Timely management is of utmost importance. Drainage of purulent collections should be performed as in the general population. (24) (see Appendix I).

SECTION II: SYNERGISTIC NECTROTIZING SOFT TISSUE INFECTION IN THE PERINEUM

CASE STUDY

A 48-year-old non-diabetic man, paraplegic (secondary to congenital spina bifida cystica) was brought to the ED by a friend because of apathy, lightheadedness, fever and malaise with sweating but denied any pain. He practices bladder self-catheterization and is able to care for himself for affairs of daily living. He spends all day and evenings in his wheelchair and is able to transfer himself to and from his bed. His oral temperature is 38.6C (101.5°F). The WBC is 3,100/mm³ with 46% bands. The blood urea nitrogen (BUN) is 48 and creatinine is 3.0 mg/dl. His heart rate is 132 beats per minute and respiratory rate is26 breaths per minute. BP is recorded as 88/40 mm Hg. A Foley catheter is placed and 120 ml of dark, malodorous urine is recovered. Physical examination reveals a large, necrotic, full-thickness left ischial decubitus with black circumferential margin, local edema, nearby skin erythema, and dark-colored skin blisters (Figures 57.2 and 57.3). A plain X-ray shows soft tissue gas. He is resuscitated with 2 L of IV crystalloid with rapid improvement in hisBP, but he remained tachycardic. He was taken urgently to the OR for incision, drainage, and debridement of aggressive perineal infection after initiation of broad-spectrum antibiotics (Figures 57.4 and 57.5).

Figure 57.2 Necrotic decubitus with surrounding cellulitis and edema.

Figure 57.4 Debridement of all infected and devitalized tissue.

Figure 57.3 Full-thickness decubitus with central necrosis and surrounding cellulitis.

Figure 57.5 Exposed left testicle and spermatic cord.

DEFINITIONS, BACKGROUND AND DIFFERENTIAL DIAGNOSIS

Necrotizing infections of the perineum have been referred to in the literature by several different names, which may cause confusion for the unfamiliar reader. Descriptors and synonyms include 'necrotizing fasciitis (NF),' 'synergistic soft tissue gangrene,' 'Meleney's synergistic gangrene,' 'gas gangrene,' and 'Fournier's gangrene.' Terms such as 'clostridium gas gangrene,' 'clostridial myonecrosis,' 'clostridial NF,' and 'non-clostridial anaerobic infection' reflect the frequently associated microbial culprit in the infection.(25) Despite the frequent use of the term 'myonecrosis' to describe these infections, only a very small minority develops clostridial myonecrosis (26) and not all infections of similar appearance and virulence have clostridia amongst the pathogens.(27) The description of the syndrome as '"hospital gangrene' was provided by Joseph Jones, an army surgeon in the American Civil War in 1871.(28)

The term 'Fournier's gangrene' recognizes the l883 report by the French venereologist Fournier of five young men with rapid progression of gangrene of the scrotum and penis without obvious cause identified.(29) Since then, the term has been applied to most necrotizing subcutaneous infections of the perineum in males and females. The etiology of Fournier's cases have subsequently been attributed to possible trauma of the scrotum where there is thought to be poor hygiene. A large number of cases have been identified, however, in which trauma cannot be blamed as a factor.(30) 'NF' was first named by Wilson in 1952. It is a rapidly spreading and potentially life-threatening soft tissue infection. Distinguishing NF from non-necrotizing infections such as simple abscess and cellulitis is often difficult. Hey et al. (31) have classified NF into the three most notable syndromes, which provides a useful framework for understanding and studying these important infections (Table 57.II-1).

Table 57.II-1 A Classification of Notable Syndromes of Necrotizing Fasciitis (NF).

Type I NF: polymicrobial and usually occurs after trauma or surgery, or in urogenital and anogenital infections

Type II NF: group A streptococcal infections ('flesh-eating bacteria')

Type III NF: clostridial myonecrosis (gas gangrene)—associated with surgery and trauma

CLINICAL FEATURES OF THE DISEASE

Pain, fever, relative tachycardia, erythema with purplish black discoloration at or near the site of origin, hypotension, extreme tenderness, profuse, 'dish-watery,' serous drainage from ruptured bullae, local edema, crepitant local tissue and mental status changes are common manifestations of the clinical presentation. Frequently, gas can be observed in the tissues on plain radiographs or CT scans. CT scan should be readily obtained if there is a strong suspicion for deep perineal, perianal or supralevator abscess, or cellulitis when plain films are non-diagnostic or equivocal. Radiographs and CT images demonstrate full gas bubbles within the soft tissue, which dissect into intramuscular fascial planes and muscles. Non-clostridial soft tissue infections have been suggested to produce abundant gas, in contrast to relatively less production by the clostridium organism.(32) Many of these infections can be insidious in onset, resulting in delay of diagnosis and initiation of appropriate therapy. Some of the presenting signs and symptoms of NF are similar to those seen in superficial soft tissue infections. In a study of severe soft tissue infections in extremities by Zahar et al. it was shown that in surgically confirmed cases, patients with NF more often had focal skin areas of ischemia or necrosis, fluid-filled vesicles, and sepsis compared to patients with superficial soft tissue infections.(33)

Our patient demonstrates the systemic inflammatory response syndrome (SIRS) which is frequently present in these patients (fever tachycardia, tachypnea, WBC less than 4,000 per mm^3 or greater than 12,000 per mm^3 or bandemia). Elevated hepatic transaminases and jaundice are indicative of systemic toxicity and the development of multiple organ dysfunction syndrome. Azotemia and renal failure are common, particularly in patients with late presentations and pre-existing renal insufficiency. Metabolic acidosis may result from intravascular volume depletion resulting from edema, and from acute renal failure, secondary to volume sequestration as well as cytokine-mediated depression of renal function. Diabetic ketoacidosis should be looked for in this syndrome, which most commonly occurs in patients with diabetes mellitus. There is no evidence that the syndrome is more frequent in insulin-dependent compared to non-insulin-dependent patients. Diabetics appear to be at increased risk as a result of impaired phagocytosis and chemotaxis, and altered lymphocyte function with cytokine overproduction. Correlation between IL-6 levels and severity of soft tissue infection in patients with diabetes has been reported.(25)

Non-diabetic patients that present with perineal necrotizing soft tissue infection are rare. However, diabetics with other co-morbidities such as obesity, low cardiac output cardiac disease, low socio-economic status, chronic obstructive pulmonary disease , alcohol abuse, hepatic cirrhosis (Hepatitis C disease), renal failure, IV drug abuse, HIV infection, peripheral vascular disease, hypoalbuminemia, and cancer may be at the highest risk. Older non-diabetic patients with decubiti represent another commonly seen risk group, particularly when they reside in nursing homes. Contributing to the pathogenesis of necrotizing soft tissue infection seems to be poor tissue blood supply, the number of bacteria, and the integrity of host defense.

Paramount to making the diagnosis is recognition of signs of tissue necrosis, putrid discharge, severe pain, bullae, rapid burrowing through fascial planes, and lack of the classic signs of tissue inflammation. Without treatment, secondary infection of the muscle layers occurs, resulting in myositis or myonecrosis. Significant easily detectable undermining of normal skin and subcutaneous tissue at a distance from the site of origin or irritating wound is frequently identified. Rarely, in addition to spontaneous infections in immunocompromised hosts, surgical procedures (hemorrhoidectomy, anal fistulotomy) may create local tissue injury and promote bacterial invasion, leading to NF. Minor insect bites have also been the source of necrotizing infections.

BACTERIOLOGY OF PERINEAL NECROTIZING FASCIITIS

Common aerobes isolated from patients with NF include gram-positive staphylococci and streptococci, and enteric gram-negative rods. The most common anaerobes are the gram-positive streptococci and gram-negative bacteroides. It is common to have multiple organisms collected. Clostridium is cultured in a number of patients. *Vibrio vulnificus* and *V. parahemolyticus* are more rare, but important, causes of NF. Systemic fungi have also been identified in these infections as monomicrobial culprits and in combination with bacteria. Microbiologic study of our patients at The University of Toledo Hospital show anaerobes as the source of mono and poly infections, combinations of aerobic and anaerobic isolates, and gram-negative aerobes in the same patient (Table 57.II-2). Mortality in such patients is high, usually due to SIRS and multiple system organ failure. The causative organism cannot be deduced from the clinical picture; nor can a correlation be made between organisms and severity or course of the illness.(3) Most of these infections are community acquired, and tremendous antibiotic resistance would not be expected. Some patients, however, live in nursing homes or have had frequent hospitalizations where exposure to resistant organisms is high. Antibiotic selection must be based on the local hospital or community antibiograms in institutions with high nosocomially acquired resistant organisms.

How is necrotizing soft tissue infection of the perineum best treated?(See Table 57.II-3)

Our clinical experience and descriptions from the surgical literature support the following principles of management of necrotizing perineal sepsis:

- Broad-spectrum antibiotics in doses adequate to achieve high antibacterial drug levels, followed by drug de-escalation once specific culture and sensitivity information is available (Table 57.II-4).

Table 57.II-2 Dominant Pathogens in Necrotizing Fasciitis (NF).

Mixed aerobes and anaerobes
Aerobic *Enterobacteriacea* family (small, non-spore forming bacilli) (coliforms)
Enterobacter
Escherichia coli
Klebsiella
Kluyvera
Proteus, Providencia, Morganella (all closely related)
Serratia
Acinetobacter
Anaerobes
Bacteroides fragilis
Clostridium perfringens
Propionibacterium acnes
Bacteroides spp.
Actinomyces
Peptostreptococcus
Pseudomonas aeruginosa (aerobic)
Rarely encountered bacteria:
Mycobacterium ulcerans
Stenotrophomonas maltophilia
Bacillus cereus
Vibrio vulnificus
Fungi
Curvularia brachyspira
Alternaria spp.
Apophysomyces elegans (subtype *mucormycosis*)
Zygomycosis

- Aggressive resection of all devitalized tissue (dead tissue is a nidus for continued bacterial proliferation and inflammatory cytokine stimulation).
- Close observation of wounds with the goal of early recognition of the development of additional dead tissue in need of debridement.
- Return to the OR as often as necessary (multi-staged necrotomies) to control devitalized tissue and ongoing SIRS.
- Laboratory studies should not be used as the sole basis for the decision to perform operative exploration. Their sensitivity and negative predictive value are inadequate.
- Vigorous IV fluid and electrolyte resuscitation and circulatory support.
- Early ventilatory support of patients developing tachypnea, hypoxemia, radiographic pulmonary infiltrates, and ventilation-perfusion mismatch.
- Nutritional supplementation.
- A high index of suspicion and urgent surgical drainage and debridement.

Over the last 15 years, there have been several case reports and retrospective reviews of experience with hyperbaric oxygen (HBO) therapy for necrotizing soft tissue infection. Patients have been exposed to 2.5–3 atmospheres (ATA) for 90 minutes, each three times in the first 24 h of the diagnosis and twice daily, utilizing up to 15 total treatments. No randomized controlled trials have

Table 57.II-3 Evidence-Based Recommendations for Best Treatment of Necrotizing Fasciitis (NF).

Treatment Recommendation	Grade of Recommendation
Broad-spectrum antibiotics in addition to surgical debridement to achieve resolution of necrotizing soft tissue infection	1B
Initial aggressive resection of devitalized tissue is mandatory to control sepsis	2C
Repeat debridement is useful for residual devitalized tissue	2C
HBO therapy improves outcome	2C

Table 57.II-4 Antibiotic Choices for Presumptive Treatment of Necrotizing Fasciitis (NF)[a].

Type I NF: (coliforms and anaerobes)
cefotaxime (2–4 gm IV q.8h) + clindamycin (600–900 mg IV q.8h), or piperacillin/tazobactam (2.25–3.375 gm q.6h), or ampicillin/sulbactam (1.5–3 gm IV q.h.), or ticarcillin/clavulanate, imipenem
Satisfactory coverage of MRSA requires addition of vancomycin, linezolid (600 mg IV q.12h), or clindamycin to the above regimens
Alternatives
linezolid + meropenem (1 gm IV q.8h); linezolid + piperacillin/tazobactam
Type II NF: (streptococcal "flesh-eating bacteria")
penicillin + clindamycin (inhibits toxin production[b])
Type III NF: (clostridial myonecrosis)
metronidazole or clindamycin
(Antibiotic therapy should be de-escalated and targeted to results of wound and blood cultures when available)

[a](http://prod.hopkins-abxguide.org/diagnosis/soft_tissue/necrotizing_fasciitis.html?contentInstanceId = 255447)

[b]Majeski JA, John JF Jr. Necrotizing soft tissue infections: a guide to early diagnosis and initial therapy. South Med J. 2003; 96(9): 900–905

been published to support the effectiveness suggested by some authors. Results of published studies have been mixed and the specific role played by the HBO therapy above and beyond the established treatment by surgical debridement and antibiotics has not been elucidated. HBO appears to increase normal oxygen saturation in infected wounds by a thousandfold.(34) Studies in which subcutaneous oxygen tension has been measured, levels were reported to increase fivefold and the carbon dioxide tension levels twofold compared to initial levels. In patients with NF, pO_2 levels were regularly higher in the vicinity of the infected area than in healthy tissue.(35). This hyperoxygenated tissue zone surrounding the infected area is postulated to be of significance in preventing the extension of invading microorganisms. This could be important in limiting the number of required debridements, which could reduce the number of hospital days, procedures and their consequent costs.

Problems with the available published reports are inconsistency of findings in NF and Fournier's gangrene. Few centers have HBO capability and the time and arrangements required to transport

Figure 57.6 Clean, healthy wound after debridement, wound care and antibiotics.

Figure 57.7 Closed wound with complete resolution of infection.

patients to centers of excellence in HBO therapy do not make this modality practical for a very significant number of the patients struck with this disease. Our interpretation of the data and our own experience suggest that HBO should be used in ill patients as part of a multimodality treatment approach following aggressive surgical debridement, when available.

CONCLUSION

Necrotizing skin and soft tissue infections are an important challenge for the acute care surgeon. The initial presentation may be insidious and result in delay in diagnosis and timely therapy. A spectrum of infectious diseases result in necrosis of the skin and soft tissue in patients predisposed by diabetes mellitus, trauma, insect bites, drug reactions, illicit drug injections, perirectal abscesses, and operative procedures.(36) There seems to be a frequent association of these infections with chronic diseases, such as congestive heart failure, obesity, renal insufficiency, cancer, malnutrition, arteriosclerosis, alcoholism, autoimmune disease, acquired immunodeficiency and immunosuppression as well as old age. However, approximately 30% of these infections occur in healthy individuals without apparent underlying risk factors.(34) Gas is frequently noted in the soft tissues radiographically, but the sign of tissue crepitus is found in only 50% of the patients. Toxic shock syndrome can be identified in most patients with large amounts of tissue gas.(37) In the era of acute care surgery as a team discipline, it is especially important that there is a high index of suspicion for this diagnosis and that aggressive early intervention is carried out before patients are signed off to others who might be given a false sense of security about such a patient not deemed to be critical at sign out, leading to further delay in diagnosis and treatment and poor patient outcome.

The surgeon must always follow the basic principles of complete excision of all necrotic tissue, establishment of wide surgical drainage, attention to hemostasis, selection of appropriate initial broad-spectrum antibiotics, aggressive fluid and electrolyte resuscitation, and close follow-up. Excellent results can be achieved

when these principles are followed and the patient outcomes can be professionally quite satisfying (Figures 57.6 and 57.7).

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Appendix I: Evidence-Based Recommendations for the Treatment of Perianal and Perirectal Abscess

1. Surgical drainage of perianal and perirectal abscesses is sufficient without the need for systemic antibiotic therapy. *1B*
Stewart MP, Laing MR, Krukowski ZH. Treatment of acute abscesses by incision, curettage and primary suture without antibiotics: a controlled clinical trial. Br J Surg 1985; 72(1): 66–7.
Llera JL, Levy RC. Treatment of cutaneous abscess: a double-blind clinical study. Ann Emerg Med 1985; 14(1): 15–9.
Macfie J, Harvey J. The treatment of acute superficial abscesses: a prospective clinical trial. Br J Surg 1977; 64(4): 264–6.

2. Prophylactic antibiotic therapy is indicated for the prevention of endocarditis in patients with prosthetic valves, previous endocarditis, unrepaired cyanotic congenital heart disease, or cardiac transplantation recipients who develop cardiac valvulopathy. *1C*
Wilson W, Taubert KA, Gewitz M et al.; American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee; American Heart Association Council on Cardiovascular Disease in the Young; American Heart Association Council on Clinical Cardiology; American Heart Association Council on Cardiovascular Surgery and Anesthesia; Quality of Care and Outcomes Research Interdisciplinary Working Group. Prevention of infective endocarditis: guidelines from the American Heart Association: a guideline from the American Heart Association Rheumatic Fever, Endocarditis, and Kawasaki Disease Committee, Council on Cardiovascular Disease in the Young, and the Council on Clinical Cardiology, Council on Cardiovascular Surgery and Anesthesia, and the Quality of Care and Outcomes Research Interdisciplinary Working Group. Circulation 2007; 116(15): 1736–54. Epub 2007 Apr 19. Erratum in: Circulation 2007; 116(15): e376–7.

3. The main cornerstone of treatment of perianal and perirectal suppurative disease is drainage of the pus. This is accomplished by incision and drainage followed by packing the wound open, insertion of a mushroom tip catheter, or even wound closure. *1C*
Isbister WH. A simple method for the management of anorectal abscess. Aust N Z J Surg 1987; 57(10): 771–4.
Stewart MP, Laing MR, Krukowski ZH. Treatment of acute abscesses by incision, curettage and primary suture without antibiotics: a controlled clinical trial. Br J Surg 1985; 72(1): 66–7.
Read DR, Abcarian H. A prospective survey of 474 patients with anorectal abscess. Dis Colon Rectum 1979; 22(8): 566–8.

4. Primary fistulotomy at the time of initial drainage of perianal suppurative disease reduces the recurrence rate but may increase the risk of incontinence to flatus and stool. *2A.*
   Quah HM, Tang CL, Eu KW, Chan SY, Samuel M. Meta-analysis of randomized clinical trials comparing drainage alone vs primary sphincter-cutting procedures for anorectal abscess-fistula. Int J Colorectal Dis 2006; 21(6): 602–9.
   Ho YH, Tan M, Chui CH et al. Randomized controlled trial of primary fistulotomy with drainage alone for perianal abscesses. Dis Colon Rectum 1997; 40(12): 1435–8.
   Tang CL, Chew SP, Seow-Choen F. Prospective randomized trial of drainage alone vs. drainage and fistulotomy for acute perianal abscesses with proven internal opening. Dis Colon Rectum 1996; 39(12): 1415–7.

5. Drainage of a deep postanal space abscess involves a posterior midline incision that severs the lower edge of the internal sphincter and the subcutaneous external sphincter. *1C*
   Hanley PH. Conservative surgical correction of horseshoe abscess and fistula. Dis Colon Rectum 1965; 8(5): 364–8.
   Inceoglu R, Gencosmanoglu R. Fistulotomy and drainage of deep postanal space abscess in the treatment of posterior horse-shoe fistula. BMC Surg 2003; 3: 10.

6. A supralevator abscess that points towards the rectum should be drained intrarectally. Otherwise, they should be drained externally if it is a superior extension of an ischiorectal abscess. *1C*
   Prasad ML, Read DR, Abcarian H. Supralevator abscess: diagnosis and treatment. Dis Colon Rectum 1981; 24(6): 456–61.

7. Intersphincteric anal abscesses should be drained into the anal canal by division of the overlying internal sphincter muscle. *1C*
   Millan M, García-Granero E, Esclápez P et al. Management of intersphincteric abscesses. Colorectal Dis 2006; 8(9): 777–80.

8. In infants, successful treatment of perianal abscesses can be accomplished by antibiotics alone. *1C*
   Christison-Lagay ER, Hall JF, Wales PW et al. Non-operative management of perianal abscess in infants is associated with decreased risk for fistula formation. Pediatrics 2007; 120(3): e548–52.
   Serour F, Somekh E, Gorenstein A. Perianal abscess and fistula-in-ano in infants: a different entity? Dis Colon Rectum 2005; 48(2): 359–64.

Appendix II: Evidence-Based Recommendations for the Treatment of Perineal NF.

Broad-spectrum antibiotics are necessary in addition to surgical debridement to achieve resolution of necrotizing soft tissue infection.

Aggressive resection of all devitalized tissue is mandatory to control sepsis.

Repeat debridement when there is residual devitalized tissue improves outcome and is a mandatory component of successful management.

HBO therapy should be used when the modality is available.

58 Necrotizing soft tissue infections
Lisa Ferrigno and Andre Campbell

A 50-year-old man with a history of hypertension and diabetes presented with a 2-day history of increasing left lower quadrant (LLQ) abdominal pain. He noted previous episodes of crampy abdominal pain that resolved spontaneously; he attributed these episodes to gas. Over the previous 2 days, the pain had escalated and was constant. He had passed neither flatus nor had a bowel movement since the pain started. Additionally, he was mildly nauseated and felt feverish and bloated. On presentation, his temperature was 101.5°F, he appeared uncomfortable. His heart rate was 110 beats/min and his BP was 110/60. His oxygen saturation was 100% on room air. On physical exam, his obese abdomen was moderately distended and he had guarding over the LLQ. Laboratory evaluation yielded: white blood cell (WBC) count = 18,000/mm³, hematocrit (HCT) = 45%. His chemistries were significant for: Na = 133, K = 5.0, HCO_3 = 22, blood urea nitrogen (BUN) = 40, creatinine = 1.6, glucose = 350. His urinalysis (UA) was negative for ketones. A diagnosis of perforated diverticulitis was suspected. A computed tomography (CT) scan was performed and free intraperitoneal air with fluid was noted with, and no definitive collection was amenable to drainage.

After discussion with the patient and his family, he was taken to the operating room for a Hartmann's procedure after appropriate resuscitation was initiated, including fluid, antibiotic treatment, and insulin administration. He did well intraoperatively and was extubated in the operating room. The patient was then transferred to the step-down unit on Ciprofloxacin and Flagyl, with a nasogastric tube and on an insulin drip. He required a 2 l fluid boluses early postoperatively, but ultimately his fluid rate was lowered and he was awaiting transfer to the floor on postoperative day (POD) 2.

In the middle of his POD 2, his urine output dropped precipitously and did not respond in a sustained fashion to fluid boluses. He spiked a fever to 39°C. Repeat labs demonstrated an increased WBC (35,000), increased BUN, and creatinine. An insulin drip was restarted because his blood glucose level became elevated again. He began to become agitated and his oxygen saturation decreased. An arterial blood glass at this juncture was: ph = 7.32, pCO_2 = 30, pO_2 = 75, HCO_3 = 22, base excess = −8. At this point, he was transferred to the ICU and intubated. Intra abdominal infection was suspected and a work-up of possible causes was initiated and his antibiotic coverage was broadened. His midline wound was inspected for evidence of a wound infection. The

stoma appeared viable; later in the day, however, the nursing staff changed the stoma bag and noted surrounding erythema. The surgical house staff was notified, and on inspection, there was an area of erythema, induration, and crepitus around the stoma. A CT scan was performed which demonstrated a large amount of subcutaneous emphysema around the stoma site that was extending into the abdominal wall.

The family was contacted and updated on the change in clinical course and consent was obtained for operative exploration and possible abdominal wall debridement with the suspicion of soft tissue infection. In the operating room, the midline wound was reopened and the stoma was taken down. The surrounding soft tissue was noted to be pale with copious thin grey fluid of dishwater consistency present in the wound. There was minimal bleeding from the subcutaneous fat; the fascia appeared healthy and was adherent to the underlying muscle. The muscle itself also appeared healthy and had good backbleeding. The subcutaneous tissues and overlying skin were debrided until healthy tissue was encountered, encompassing the area circumferential to the stoma site and extending medially to the midline. A temporary closure apparatus was placed over the wound and the patient was brought back to the intensive care unit (ICU) with the intention of a second look operation in approximately 24 h. The colon was left stapled in the abdomen.

In 24 h, re-exploration was performed; a minimal amount of necrotic tissue was further debrided and again closed temporarily. The following day, fluid requirements were down; fever and hemodynamics were improved. The wound appeared viable. A new stoma was brought out on the right side of the abdomen and matured; the fascia was closed using #1 Prolene sutures and retention sutures. The wound was initially managed with frequent wet to dry dressings and on POD 3, was changed to a vacuum dressing device with the intention of skin grafting in the remote future.

OVERVIEW

Epidemiology
Overall incidence data in a general population are lacking. The Centers for Disease Control estimates that there are 500–1,500 necrotizing fasciitis cases each year attributable to Group A *Streptococcus* (1), the only organism which is reportable. Table 58.1 outlines various studies, all single center, the year that they were published, mortality rates, and the number of patients treated. As

Table 58.1 Single Center Published Experiences with Necrotizing Fasciitis, Including Mortality Rates.

Study	Year Published	Percent Mortality	Total number
Hsiao et al	2008	19	128
Gunter et al	2008	9.6	52
Bilton et al	1998	21	68
Elliott et al	1996	25	198
Bosshardt et al	1996	27	28
McHenry et al	1995	29	65
Brwon et al	1994	35	54
Chow et al	1993	25	12
Francis et al	1993	24	25
Wang & Shih	1992	33	13
Ward & Walsh	1991	43	14
Asfar et al	1991	30	10
Clayton et al	1990	18	57
Sudarsky et al	1987	6	33
Gozal et al	1986	12	16
Freischlag et al	1985	35	21
Pessa & Howard	1985	33	33
Barzilai et al	1985	36	11
Stamenkovic & Lew	1984	42	19
Spirnak et al	1984	45	20
Adinolfi et al	1983	27	11
Miller	1983	27	15
Walker & Hall	1983	38	8
Majeski & Alexander	1983	33	30
Rouse et al	1983	73	27
Oh et al	1982	36	28
Freeman et al	1981	29	14
Kaiser & Cerra	1981	40	20
Casali et al	1980	33	12
Total		26	1042
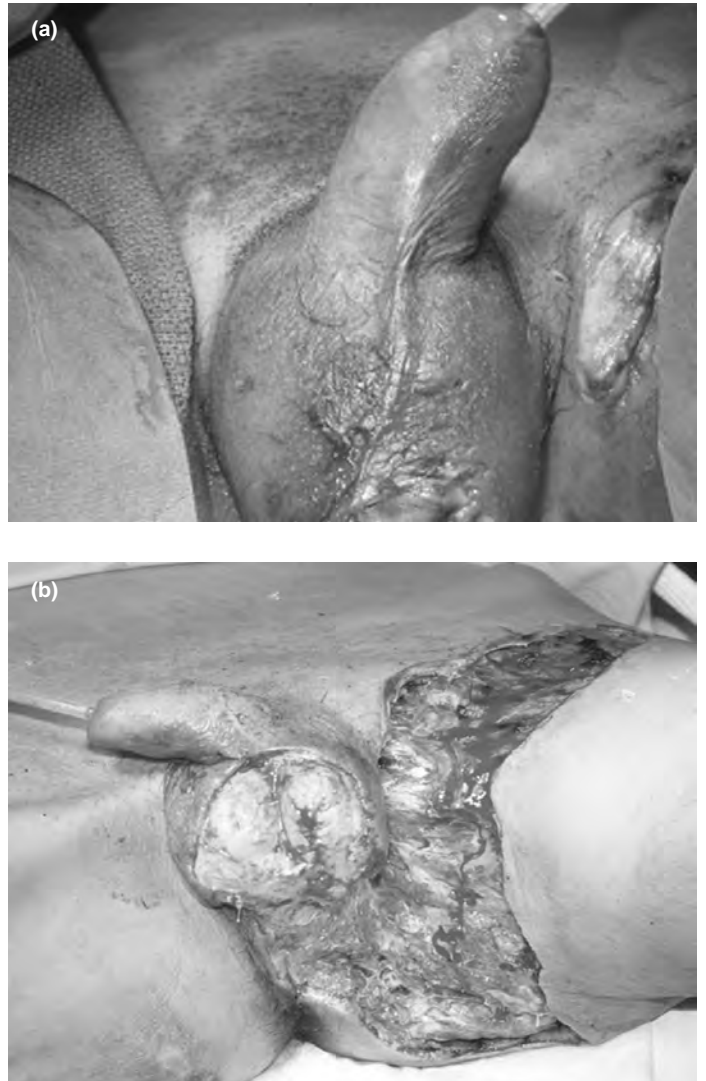
Figure 58.1 a) A 50 year old diabetic, obese male at the time that his primary team requested surgical consultation with Fournier's gangrene. Skin changes had progressed to frank necrosis in the groin and scrotum.
b) Initial debridement.

is characteristic of this disease entity, published reports are single center, and variability exists in the time period covered. There is some feeling, reflected in the literature, that the number of serious soft tissue infections is growing, but based on single center experiences. Additionally, while some authors report variation in mortality rates over time, perhaps indicating changes in the virulence of causative organisms or access to care, these trends are impossible to follow as currently reported.

There would be utility in regional tracking of these serious infections and their outcomes to know if these observations are true or reflective of bias or changes in practices, such as an increase in patient transfers to tertiary care centers that may be able to offer more comprehensive care that may influence single site experience.

Spectrum of Disease

Necrotizing soft tissue infections (NSTI) are known under a vast number of names, including necrotizing faciitis, necrotizing myositis, "flesh eating" strep, and others over the years. "Hospital gangrene" was described by Confederate Army surgeon Joseph

Jones after a study in 2,642 persons, with a 46% mortality rate.(2) All are forms of NSTI. Some of the nomenclature has developed to be associated with a particular site, that is, Ludwig's angina for infection of the submandibular space and Fournier's gangrene for NSTI of the perineum (see Figure 58.1).

The confusion associated with the nomenclature may lead to confusion in making the diagnosis, which, as will be discussed subsequently, may lead to delay in therapy with devastating consequences.

Necrotizing cellulitis has been described, may cause skin changes such as bullae and, in this case, as the differential may include Stevens Johnson, autoimmune causes such as pemphigus, and so on, an infectious/histologic diagnosis should be sought. Should be changed to: Necrotizing cellulitis has been described and may cause skin changes such as bullae. In this case, the process is superficial and the differential should also include noninfectious causes, such as Stevens Johnson syndrome and pemphigus, among others. The overall clinical picture should guide the workup which may be aided by early histologic tissue evaluation.
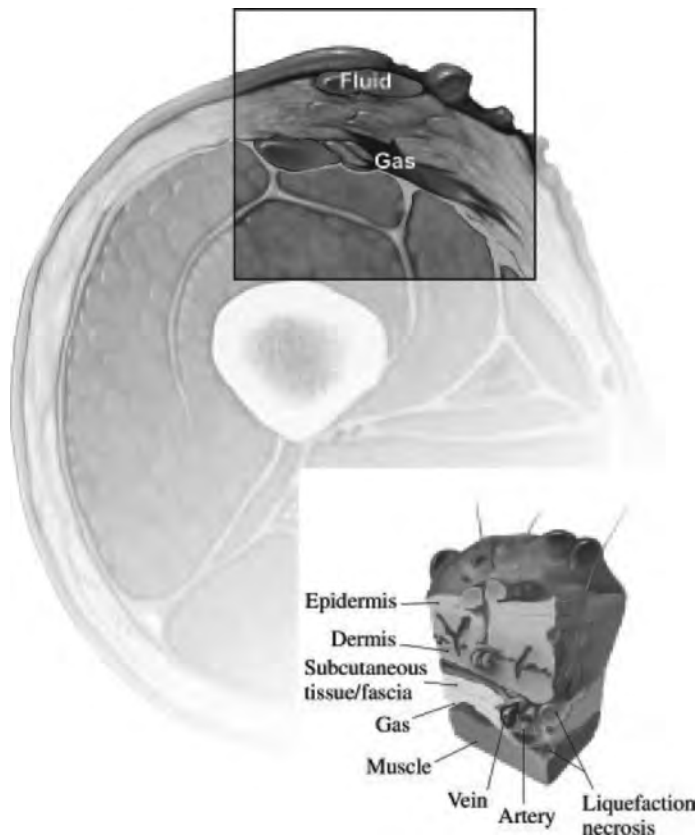
Figure 58.2 a) Illustration of tissue changes in necrotizing fasciitis. (Source: Musculoskeletal infection: role of CT in the emergency department. Source: Radiographics [0271-5333] Fayad, Laura M yr:2007 vol:27 iss:6 pg:1723–36)

More frequently, however, the practitioner may be attempting to differentiate between a skin infection (cellulitis) and a deeper soft tissue infection. The difference is *not* purely academic. Treatment of cellulitis is medical whereas treatment of soft tissue infections is surgical, and delay to treatment may rapidly progress to multisystem organ failure and death.

Necrotizing soft tissue infections usually involve structures deep to the dermis such as the subcutaneous fat, fascia, and muscle, either alone or in combination. The mechanism leading to the infection may help explain the presentation; for example, a gun shot wound to the deep compartment of the leg could feasibly lead to subsequent necrotizing myositis in the deep compartment, the more superficial structures spared and the usual superficial findings absent.

Common histologic features include: extensive tissue necrosis, abundant bacteria in tissue planes, and small vessel thrombosis as depicted in Figure 58.2. Cultures may yield a single organism or be polymicrobial.

Patients may present in fulminant septic shock. Many present with signs of toxemia. It's likely possible that more indolent courses are possible, however, as delay to definitive operative therapy portends a worse outcome, the safer and, hence, conservative approach once the diagnosis is suspected, is for immediate surgical exploration. If the diagnosis is still in question at the time of exploration, tissue may be sent for pathologic evaluation and

cultures, and the patient may be closely observed for signs of clinical deterioration or lack of response to medical management.

DIAGNOSIS

The mainstay of diagnosis is the clinical picture. Although other diagnostic modalities, specifically radiographic, exist and will be discussed, clinical suspicion should prompt immediate surgical consultation by emergency surgical specialists, if available. Although the experienced primary care clinician may see only a handful of cases in a lifetime of practice, emergency surgeons within a referral center may evaluate such pathology regularly. Adjunctive studies should not delay consultation, nor should one wait until laboratory or radiographic studies are available to obtain surgical consultation.

The surgeon may entertain employing radiographic studies; however, in the presence of high clinical suspicion, results may confirm clinical suspicions; negative studies in the presence of high clinical likelihood, especially if the clinical condition of the patient shows no improvement or deterioration, are not helpful and may be harmful if they delay definitive surgical therapy. Exploration by an experienced surgeon should be undertaken, and possibly tissue should be sent for microscopic evaluation and cultures, if the diagnosis remains in question.

The patient, unless obtunded, may complain of pain out of proportion to the physical findings and may indicate a nidus, that is, a bug bite (although absent in at least 20% (3) and absent in 31% in one recent series (4)). All patients in one study complained of pain, swelling, and fever (5), however, some studies have noted that only one-third of patients had or complained of fevers.(6, 7)

Site findings may include: erythema, induration, and skin changes such as bullae, blisters, crepitus, and warmth. Complaints of pain may be out of proportion to physical findings. Induration and edema are often of a tense or woody nature. Focal fluctuance with abscess is not identified. Crepitus and bullae, when apparent, should readily differentiate simple cellulitis from a deeper infection; however, these findings are found variably.(6, 8) Clinical manifestations include nonspecific findings of toxemia and may include fever, leukocytosis, leukopenia, tachycardia, hypotension, electrolyte abnormalities, florid or impending renal or respiratory failure, academia, and altered mental status.

Attempts to create a model for prediction of NSTI versus less morbid soft tissue infection have been made. Based on 31 NSTI cases, Wall et al. (9) described a model based on WBC and serum sodium; while negative predictive value was found to be high, positive predictive value was only 26%, suggesting this algorithm may be useful for ruling out NSTI. Another tool, the laboratory risk indicator for necrotizing fasciitis (LRINEC) was developed based on 89 NSTI cases (10), with modeling based on six laboratory variables with a suggested scoring system based on these variables. Cutoffs were established for suspicion of disease; its positive predictive value was found to be 93%. This population, however, may have important differences than other populations: there were no HIV-positive individuals and 71% of cases had diabetes, for example. Table 58.2 provides a descriptive summary of some of the studies characterizing their NSTI populations. Two of these studies, by Wong and Su, provided the proposed laboratory based evaluation tool, while the other provided validation of the tool, respectively. Other studies (11, 12, 13) characterize their institutional experience with NSTI
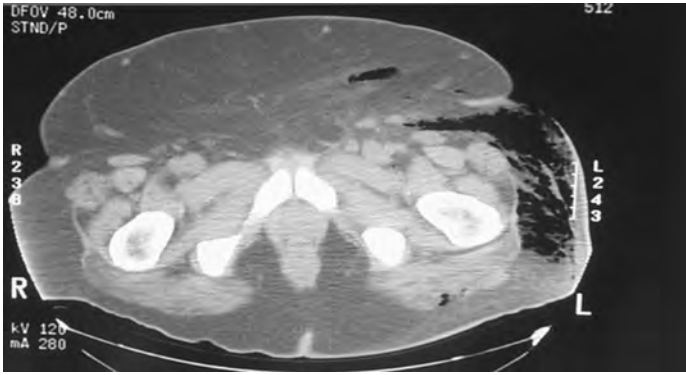
Figure 58.3 CT scan of the patient described in the case described demonstrating characteristic appearance of necrotizing soft tissue infection, with air tracking along the subcutaneous fat and other soft tissues.

while the largest single institution description by Elliott et al. attempts to ascertain factors for mortality risk. By no means exhaustive, this table is meant to highlight some of the differences in the populations, presentations, and outcomes in the reported literature. One readily noticeable difference is the time to the operating room for first debridement, a factor found to be consistently important with respect to outcome. There is wide variability in time to the operating room; additionally, this is not defined as whether it was time from initial symptoms or presentation to the surgical service. Although a model incorporating readily available clinical characteristics would be helpful in differentiating simple cellulitis from an NSTI, such a model would be based on a large population with multiple centers in order to be generalizable to multiple populations.

Plain X-ray may demonstrate air within the soft tissues. Without recent disruption of the soft tissue, as with recent surgical intervention, this finding is pathognomonic and no further work-up is necessary.

CT scan and magnetic resonance imaging (MRI) may be helpful in discerning noncomplicated cellulitis from an NSTI in cases where other clinical information is equivocal. CT is particularly helpful if there is gas within the deep tissues as seen in Figure 58.3 that is not palpable as crepitus on physical exam or plain X-ray; (14) indeed, CT is preferable to MRI for the detection of gas within the tissues. A CT scan may also show edema within the tissues.

MRI scan is more sensitive to these findings. Particularly, differentiation between necrotizing and a non-necrotizing infection may be possible (15) but some feel that it may lead to overestimation of the extent of disease as differentiation between infected tissues and surrounding edema is difficult.(16) Findings differentiating NSTI from simple cellulitis include linear increased T2 signal extending into intermuscular fascia. If muscle is involved, it will also show increased T2 signal within the muscle.(17) The use of CT or MRI are a very useful adjunct if there is clinical suspicion and as a roadmap for surgical planning.

In cases where there is clinical suspicion and the diagnosis is still in question, operative exploration should be undertaken as shown in Figure 58.4. Clinical features in the operating room suggestive of NSTI include pale tissues, little or no frank purulence, but, rather, pale or grayish fluid. The subcutaneous tissues are pale and do not have vigorous backbleeding. Fascia is nonadherent to overlying muscle. Some have advocated frozen section biopsy (18, 19) whether in the emergency department or operating room. Of
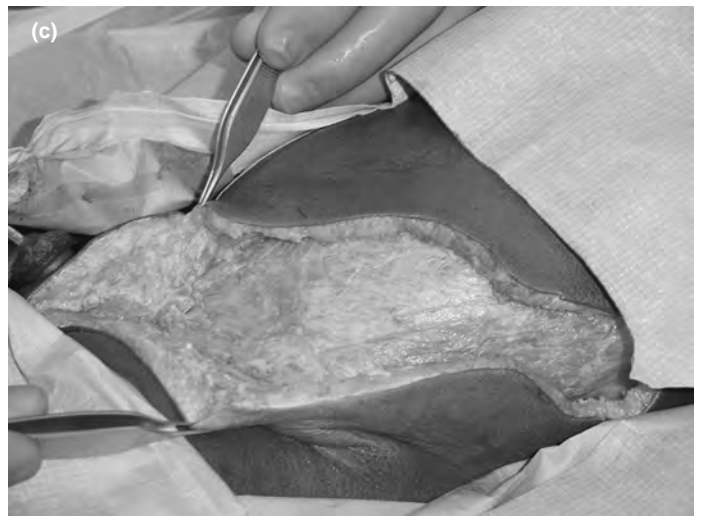
Figure 58.4 Intraoperative photo of an 18 month old male who presented with soft tissue induration and signs of sepsis. No portal of entry was identified. Photo a shows the area of induration marked as well as the initial incision made for tissue evaluation. Photos a and b demonstrate thin edema fluid and fascia that easily lifted off underlying tissue. A fascial specimen was sent to Pathology which confirmed necrotic tissue and community acquired MRSA. Photo c shows the extent of intraoperative soft tissue debridement about 12 hours later. Frank purulence and tissue necrosis grossly apparent were found tracking along the flank and into the inguinal areas.

Table 58.2 Summary of selected characteristics from reported literature on NSTIs. All values are percentages. Dashes indicate that this information was not provided by the authors.

Author (sample size)	Su (209)	Gunther (52)	Callahan (20)	Martin (20)	Wong (89)	Wall (21)	Elliott (198)	Hsiao (128)
Location	Taiwan	Nashville, TN, USA	San Francisco, CA, USA	Atlanta, GA, USA	Singapore	LA, CA, USA	Baltimore, MD, USA	Taiwan
Baseline Characteristics								
Age	56.8		40.8	42	56	39	51.5	61
Diabetes	55	46	0	25	71	14	56	59
Cirrhosis	28	13	-	-	-		4	11
Renal dz	-	-	-	10 (ESRD)	-	-	10 (azotemia)	6.2 (ESRD & CRI)
Heart disease	11.5	25	-	-	-	-	26	-
PVD	11		0		23		16	3.1
IDU	0	0	100	0		67	13	3.9 (Drug abuse, NS)
HIV (known)	0	0	10	15 (or HCV)	–	10	4	-
No comorbidities	25	–	–	-	13.5	–	-	12.5
Clinical Characteristics								
Tenderness / pain	87	–	–	-	-	–	73	55%
Erythema	86	–	77	-	-	–	66	52
Tachycardia	48	–	–	-	-	–		39.8
Bullae	45	-	3	-	-	24	24	18.8
Fever	33	–	–	45	53	–	32	43
Time to OR (hrs)	29	8.6	–	40	–	–	40.8	60
Mortality	15.8	9.6	20	0	21	29	25	19

note, there were no reported negative frozen section biopsies in these reports, therefore, weighing the availability of pathologic evaluation with delay of definitive therapy should be considered before utilization of this resource.

In the patient described, his change in clinical course was suggestive of infection. Physical findings suggested the source and CT supported a diagnosis of NSTI versus a more indolent cellulitis. CT findings were confirmatory and may be helpful in certain patients, for example, obese or if deep-seated infection is suspected and physical signs are diminutive or lacking.

RISK FACTORS

Risk factors can be grouped into two overlapping categories: host risk factors and risks for infectious inoculum.

Most individuals or the clinician are able to identify antecedent trauma to the affected area, even seemingly minor. In Elliott's series of 198 patients, only 4% had an unidentified portal of entry for infections while other, more recent series have lacked an identifiable source 20–30% of the time.(3, 4) Risks in the latter category include any apparent trauma; specifically, injections (either for prescribed or illicit drug use), varicella lesions, bug bites, and foot ulcers, particularly those found in the context of diabetes and peripheral vascular disease (PVD). The postoperative wound, particularly with bacterial or fecal contamination is at higher risk for NSTI. Frequently, there may be no obvious source of trauma.(4, 20) Other potential sources of introduction can be influenced by the surrounding population, as one might expect the rate of intravenous drug use (IVDU) and skin popping in the series reported from Los Angeles was much higher than in Dallas.(5, 8) Heroin is the agent most frequently associated with IVDU-associated NSTI, but again, might be biased according to the population reviewed, although particular forms of heroin, that

is, black tar, may indeed confer a higher risk of infections.(12) NSTIs without identifiable risk have been found to be disproportionately caused by infections with Group A *Streptococcus*, and, more recently, by community-acquired methicillin-resistant *Staphylococcus aureus* (MRSA).(21, 22)

Host risk factors include PVD, impaired cellular immunity as in HIV disease. Diabetes mellitus is present in 20–60% of adults (23, 24). Other comorbid conditions include obesity, coronary artery disease (CAD), chronic obstructive pulmonary disease (COPD), liver disease, renal disease, paraplegia, and malnutrition. Smokers, chronic steroid users, and alcohol and injection drug abusers have also been found to be overrepresented (25–28).

Variability in reports of significance of variables may reflect the difference in populations being evaluated, as discussed earlier with respect to the information provided in Table 58.2.

Microbiology

Certain characteristics may be helpful in determining the offensive organism. The presence of gas in the affected tissues, as in the case presented, are suggestive of a gas-forming organism, such as *Clostridium* spp. Other factors suggestive of *Clostridium* may be suggested by the time course; as these are toxin-mediated, signs of infection may occur sooner than with other organisms, and are associated with a more fulminant clinical course.

Monomicrobial infections are often community-acquired and trivial trauma may have been noted. Causative organisms include: *Streptococcus pyogenes*, *Streptococcus aureus*, *Vibrio vulnificus*, *Aeromonas hydrophila*, and anaerobic *Streptococci* (i.e., *Peptostreptococcus* sp.).(3)

In postsurgical patients who experience early (< 48 h) signs of infection with evidence of soft tissue infection (in this case,

Table 58.3 IDSA Guidelines for antibiotic treatment of necrotizing soft tissue infections

First-line antimicrobial agent by Infection type	Adult dosage	Antimicrobial agent(s) for patients with severe penicillin hypersensitivity
Mixed infection		
Ampicillin-sulbactam or	1.5–3.0 g every 6–8 h lv	Clindamycin or metronidazole[a] with an aminoglycoside or fluoroquinolone
piperacillin-tazobactam plus	3.37 g every 6–8 h lv	
clindamyclin plus	600–900 mg/kg every 8 h lv	
ciprofloxacin	400 mg every 12 h lv	
Imipenemy/cillastatin	1g every 6–8 h lv	…
Meropenem	1h every 8 h lv	…
Ertapenem	1g every day lv	…
Cefotaxime plus	2g every 6 h lv	…
metronidazole or	500mg every 6h lv	
clindamycln	600–900mg/kg every 8 h lv	
Streptococcus infection		
Pencillin plus	2–4 MU every 4–6h lv (adults)	Vancomyclin, linezolid, quinupristin, or daptomyclin
clindamycin	600–900 mg/kg every 8 h lv	
S. aureus infection	1–2g every 4 h lv	
Nafcillin	1–2g every 4h lv	Vancomyclin, linezolid, quinupristin, or daptomyclin
Oxacillin	1 g every 8 h lv	…
Cefazolin	30mg/kg/day in 2 divided doses lv	…
Vancomycin (for resistant strains)	600–900 mg/kg every 8 h lv	…
Clindamyclin		Bacteriostatic; potential of cross-resistance and emergence of resistance in erythromycin-resistant strains; inducible resistance in methicillin-resistant *S. aureus*
Clostridium infection		
Clindamycin	600–900 mg/kg every 8h lv	…
Penicillin	2–4MU every 4–6h iv	…

[a] If Staphylococcus infection is present or suspected, add a appropriate agent. Iv, intravenously.

erythema, swelling, and crepitus at the stoma site) infection with *Clostridium* or *S. pyogenes* (3) should be suspected.

Soft tissue infections with MRSA have increased in recent years, (29) and in some cities, the offending organism may be > 50% in patients presenting soft tissue infections. Over a 3-year period beginning in July 2000, at our institution in San Francisco, of 837 positive cultures, 695 cultures (83%) contained *S. aureus*.(30) Of these, 76% contained MRSA. Choice of antibiotic therapy should reflect this trend and, in areas where community-acquired MRSA is present and in hospitalized individuals, should include MRSA antimicrobial coverage until cultures and sensitivities are available. (3) Additionally, there are mounting reports of MRSA as the causative agent, alone or in a polymicrobial setting of NSTIs.(31, 32)

Most necrotizing soft tissue infections are polymicrobial. Antibiotic choice should therefore be initially broad and include coverage for the commonly encountered organisms mentioned earlier. Specific antibiotic coverage is discussed in the following.

Many have concomitant comorbidities which may increase risk for infection with particular organisms. For example, those in contact with marine life (frequently fishermen or shrimpers) and with hepatic disease are at particular risk for infection with *Vibrio* spp., particulary *V. vulnificus*.(33) In the series described, 40% of patients with *V. vulnificus* had hepatic insufficiency. Most of these involve an upper extremity. Mortality rates of those treated nonsurgically approach 50%. Aggressive debridement, fasciotomy, and, in necessary cases, amputation are the mainstays of surgical therapy.

Prognosis

Risk factors for mortality have been described from multiple descriptive studies. Many are inconsistent; however, time to surgical intervention may be one of the strongest and consistent predictors of outcome in both univariate and multivariate models.(7, 33, 34)

Increased age, higher WBC count, more than one system failure, extent (not depth) of initial infection, renal failure necessitating dialysis, and acute respiratory distress syndrome (ARDS) have all been found to predict higher mortality. Diabetes, particularly uncontrolled, is not only a risk factor for NSTI, but may be associated with worse outcomes, although this finding has been variable.(7) Hyperglycemia on admission, regardless of an explicit history of diabetes, may confer risk for secondary infections, thereby increasing mortality and length of stay.(34)

> The patient presented as a case example had several potential risk factors: diabetes with uncontrolled hyperglycemia on admission, obesity, and an urgent surgery with gross fecal spillage and infection.

THERAPY

Resuscitation

Frequently, patients may present hypovolemic and with toxemia. Initial resuscitation should begin immediately, with appropriate

venous access, admission to an ICU setting, and hemodynamic monitoring, as appropriate for the clinical setting. Subsequent to initial debridement, the wounds may continue to weep large amounts of fluid. In addition to fluid needs appropriate for the hemodynamic status, these losses should be anticipated. Electrolyte abnormalities should be aggressively corrected and an insulin drip considered for those who are hyperglycemic. Appropriate antibiotics should be initiated, as discussed in the following.

Surgical consultation should be sought immediately. Some patients will benefit from a short resuscitative period prior to undergoing surgical debridement; however, a planned delay to the operating room should be a decision made by the surgeon as some patients will quickly continue to deteriorate until after operative therapy has taken place.

There is some indication that the presence of emergency general surgical service may lead to an improved outcome.(34) As the presumed mechanism for this phenomenon is a decreased time to the operating room, current data do not support patient transfer to a referral center for primary operative intervention if those services are available locally. If, subsequently, additional expertise is needed, that is, the need for continuous venovenous hemodialysis (CVVHD), or anticipated need for complex wound coverage, transfer can then be sought.

Surgical

Surgical debridement is the mainstay of therapy and many studies have demonstrated that delay to the operating room is a contributing factor to increased mortality. Even if the patient is stable preoperatively, ICU management should be anticipated postoperatively.

In the operating room, incision and resection of the affected tissues should be performed. Overlying skin, even if apparently spared should be excised as it will become ischemic and serve as further substrate for infection. Careful inspection of the deep tissues should be carried out. Invariably, there is little or no gross purulence, but, there is pale, ill perfused edema fluid, or frankly necrotic tissues. The fascia may be a bit more difficult to assess. Affected fascia does not adhere to overlying muscle, and is pale without its usual glistening quality. Affected muscle is frankly necrotic, gray, and lacks bleeding when incised with a knife. All questionable tissues should be resected. If there remains a question about tissue viability, it can be decided at the second-look procedure.

Second-look procedures should be standard for NSTI, and, frequently, multiple operative procedures are required. Serial debridements should be performed. After the initial debridement, occasionally it is felt that the resection was definitive; however, the very nature of NSTI is to be rapidly progressive. Frequently, more affected tissue is found at repeat procedures and is not necessarily a reflection on inadequate first debridement but of the nature of the organism and disease progression. Attempts to conserve tissue for aesthetic purposes are not appropriate in this setting. If the patient requires many trips to the operating room keeping, the patient intubated while the surgeons gains control of the infection may allow for better pain control.

Special surgical approaches should be catered to the patient and surgical site. Extremity infections, particularly in the context of vascular insufficiency may be best addressed by amputation. Fournier's gangrene may necessitate fecal or urinary tract diversions either because of direct involvement or to facilitate wound care.

Antibiotics

Antibiotic therapy should be instituted immediately in an inpatient setting in patients demonstrating skin infection with any signs of systemic toxicity. Progression of the skin infection or increased signs of systemic toxicity should prompt surgical exploration in those who are being managed medically.

Choice of initial therapy may be guided by clinical scenario. In the patient described, surgical site infection, bowel flora exposure, and tissue suggest polymicrobial infection. Additionally, as the patient had already been on Ciprofloxacin and Flagyl, second line regimens should be considered.

In patients in whom a Staph infection is possible or suspected, coverage should be appropriate for MRSA. In areas with a high incidence of MRSA, laboratory testing for inducible Clindamycin resistance should be considered.(35)

A consensus statement from the Infectious Disease Society of America (IDSA) with initial antibiotic choice is in Table 58.3.(3)

In addition to the recommendations made by the IDSA, we recommend initial polymicrobial coverage, including coverage for MRSA, *Streptococcus*, and *Clostridium* spp. until cultures and sensitivities become available to help tailor, and possibly narrow antibiotic choices given the increasing incidence, severity and lack of reliable risk factors to identify those at risk for community-acquired MRSA infections.

Hyperbaric Oxygen

Hyperbaric oxygen (HBO) may be a useful adjunct to surgical debridement, particularly for *Clostridium myonecrosis.* Data, although potentially favorable, are limited. Studies performed have been retrospective and when a non-HBO group was used for comparison, mortality rates were frequently much higher than generally reported. In reports by Riseman (36), Brown (37), and Hollabaugh (38), mortality rates in the non-HBO groups were 66%, 42%, and 42%, respectively. Although certainly comparing favorably to the mortality rates in the HBO groups 23%, 30%, and 7%, comparison to mortality in other published series implies that there may have been selection bias in these nonrandomized reports. Additionally, HBO is likely to have a favorable effect early in the disease process. Feasibility is limited, many patients present after the inflammatory process has been initiated, and patients may clinically deteriorate prior to improving. For utilization of HBO, patients may need to be transferred to a participating facility. Additionally, maintenance of an appropriate level of care for a critically ill patient while receiving HBO is unfeasible.

Although HBO may have a theoretical role in the adjunctive treatment of some soft tissue infections, efficacy is questionable while feasibility and safety of implementation is limited.

Intravenous Immune globulin

Studies have demonstrated mixed results with respect to the use of intravenous immune globulin (IVIG) for Streptococcal-associated toxemia. The rationale stems from the fact that the toxemia associated with Streptococcal infections is secondary to extracellular toxins and that the provision of some degree of clearance of the toxins

may be obtained from IVIG. One controlled clinical trial in Europe failed to show a survival difference.(39)

Ongoing/Wound Care

The loss of tissue and inflammatory response is very similar to those being treated for burns of a comparable size. The same ancillary support, respiratory treatment (in anticipation of a prolonged vent course) physical therapy, occupational therapy, nutrition, wound nurses, and early consultation with the parties who will be involved with ultimate wound care team (i.e., burn center) should be involved. This may require transfer after stabilization to a regional burn center.

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Appendix II: Evidence-based recommendations for the treatment of perineal necrotizing fasciitis

1. Broad-spectrum antibiotics are necessary in addition to surgical debridement to achieve resolution of necrotizing soft tissue infection.
2. Aggressive resection of all devitalized tissue is mandatory to control sepsis.
3. Repeat debridement when there is residual devitalized tissue improves outcome and is a mandatory component of successful management.
4. HBO therapy should be used when the modality is available.

59 Acute intestinal obstruction

Pierre E de Delva and David L Berger

A 45-year-old male who underwent an uncomplicated appendectomy 20 years ago, presented to the emergency ward with a 2-day history of bilious vomiting, crampy abdominal pain, and obstipation. On exam, he had abdominal distention, hyperactive bowel sounds, and diffuse abdominal tenderness without peritoneal signs. A nasogastric tube (NGT) was inserted and 2 l of bilious fluid was aspirated. His laboratory evaluation was notable for a white blood cell (WBC) count of 15,000/mm^3 and prerenal azotemia. A kidney, ureter, and bladder (KUB) demonstrated dilated loops of bowel with air–fluid levels and no air in the rectum. A computed tomography (CT) scan demonstrated dilated loops of small bowel with a transition point in the ileum. There was fecalization of the small bowel, collapsed colon, and no free fluid and no free air. The patient was admitted to the surgical service for nonoperative management with NGT decompression and bowel rest. After 2 days of persistent obstipation and high NGT output, he underwent a laparoscopic exploration and lysis of a single adhesion in the right pelvis.

On postoperative day (POD) 3 he had persistently high NGT output, distention but no peritonitis on clinical exam. A CT scan demonstrated early postoperative small bowel obstruction (SBO) with no evidence of intestinal ischemia. He was managed with continued nasogastric decompression and enteral nutrition. He passed flatus on POD 10 and was discharged home on POD 12.

BACKGROUND

Intestinal obstruction is one of the most common indications for urgent surgical care, accounting for 15% of emergency ward admissions for abdominal pain.(1) An intestinal obstruction is defined as a process that mechanically impedes the flow of enteric contents and air. Anatomically, the point of obstruction is localized between the ligament of Treitz and the anus. Upper gastrointestinal sources of obstruction are rare and beyond the scope of this chapter.

There is a difference between a complete and partial bowel obstruction. A complete bowel obstruction occurs when the lumen at the site of obstruction is obliterated and there is no passage of air or enteric contents. There is complete collapse of the bowel distal to the obstruction. Partial bowel obstructions allow some, albeit restricted, passage of air and enteric contents. The distinction is important because complete bowel obstructions have an increased risk of strangulation and a lower rate of resolution with nonoperative management.

Strangulated bowel becomes ischemic from distention and excessive wall tension or from twisting of the mesentery and

disrupted blood flow. Closed loop obstructions are caused by obliteration of the lumen at both ends of a segment of bowel. There is no retrograde or antegrade passage of bowel secretions, and the segment of bowel quickly strangulates or perforates. Therefore, a closed loop obstruction requires prompt intervention. A simple bowel obstruction tends not to have an ischemic component. Consistency of terms is important to ensure accurate communication amongst the healthcare providers caring for patients with intestinal obstruction.

It is helpful to divide intestinal obstruction by anatomic location. Ninety percent of intestinal obstructions occur in the small intestine. Anatomically, a SBO extends from the ligament of Treitz to the terminal ileum. Ten percent of intestinal obstructions occur in the large intestine. Large bowel obstruction (LBO) originates between the ileocecal valve and the anus. The distinction between SBO and LBO is important because the diagnostic work-up, differential diagnosis, and treatment strategies are different.

The case patient presents with a history and physical examination consistent with intestinal obstruction.

What Is the Epidemiology of Small Bowel Obstruction?

There are multiple etiologies in the differential diagnosis of an SBO (Table 59.1). The most common cause in developed countries is adhesions from previous abdominal surgery. It is estimated that 60–85% of cases of SBO are adhesive in nature. The natural history of adhesive SBO is poorly understood. It is unclear why adhesions lead to SBO in some patients and not in others. The basic science behind the formation, nature, and density of peritoneal adhesions is understood, but not to a level to provide clinical interventions to reliably prevent their occurrence.

Postoperative adhesions are a common and costly complication of abdominal surgery.(2) It is estimated that up to 34% of patients who have had a laparotomy will be admitted to the hospital in a 10-year span for adhesive disease.(2) Although some patients present with chronic abdominal pain, the majority suffer from obstruction. The risk of developing a SBO is lifelong, 58% of patients present within 5 years of laparotomy and 14% present more than 20 years later. There are multiple risk factors for the development of adhesive SBO.(3) The risk is partially

Table 59.1. Etiologies of Small Bowel Obstruction.

Postoperative Adhesion	Midgut Volvulus
Abdominal wall hernia	Inflammatory bowel disease
Neoplasm	Foreign body
Radiation enteritis	Abscess
Bezoar	Congenital adhesion
Gallstone ileus	Intussusception

dependent upon the original operation performed. Several studies estimate that up to 80% of SBOs develop following pelvic or lower abdominal surgery, primarily gynecological and colorectal operations.(4) The extent of surgery and the presence of infection and peritonitis are also believed to affect the density of adhesions. A history of prior admissions for an SBO increases the likelihood of recurrences.(4) Multiple abdominal operations are associated with a greater number of adhesions.

Symptoms can originate from a single band or from matted adhesions. They occur in essentially equal distribution, although some operations are more prone to one or the other.(5) Single band adhesions have a higher incidence of bowel strangulation and often require operative intervention. This is most likely due to the ability of the small intestine to rotate around the solitary point of fixation. Matted adhesions tend to cause partial obstructions and chronic abdominal pain. Ischemia rarely develops because the bowel is relatively fixed and unable to twist around the mesentery.

The need for operative intervention in adhesive obstructions ranges 20–40% but it is largely dependent on the threshold for surgical intervention. Twenty percent of explorations for SBO reveal gangrenous bowel that requires resection. The long-term recurrence rate of SBO seems to be lower in patients managed operatively, but these results are based on case series with significant selection bias. No randomized data exist to guide management. The recurrence rate from both operative and nonoperative management of SBO ranges 19–53%.(5, 6)

> The patient presents with intestinal obstruction localized to the small bowel many years after the initial laparotomy. The history of an appendectomy suggests postoperative adhesions as the etiology. Appendectomy is known to be one of the more common operations associated with postoperative adhesive SBO.

It is classical surgical teaching that patients who develop SBO without previous abdominal surgery have a mechanical obstruction that can only resolve with an operation. Hernias and tumors account for a majority of nonadhesive SBOs. Tumors account for 20% of patients with bowel obstructions and the majority are malignant. Most neoplasms causing SBO are metastatic lesions, peritoneal carcinomatosis and locally advanced tumors of non-small-bowel origin. Primary small bowel tumors are a rare cause of SBO.

Hernias account for 10% of SBO. Inguinal hernias are most common but internal, lumbar, obturator, or incisional hernias can present with obstruction. Inguinal and ventral hernias are easily diagnosed in most patients. Internal hernias require a high index of suspicion. Hernias have a high risk of strangulation and need quick diagnosis and prompt intervention.

An increasing number of patients with Crohn's disease present with SBO. The presentation can be chronic and insidious. In general, urgent exploration is reserved for patients with evidence of strangulation or perforation. SBO in patients with Crohn's disease occur from either phlegmon or stricture. In most patients, a trial of nonoperative management is desirable.

Bezoars are a rare cause of SBO. Risk factors for development of large bezoars include poor dentition, previous gastric surgery and high vegetable intake. Most bezoars form in the stomach and present with delayed gastric emptying or bleeding. Rarely, a bezoar will migrate into the small bowel and cause an obstruction. The diagnosis of an obstructing bezoar can be difficult to make. These patients often fail nonoperative management and require operative intervention to relieve the obstruction.

Several nonmechanical causes of small bowel dilation are erroneously diagnosed as SBO. The increased use of CT scans in the work-up of abdominal pain has led to an increase in the sensitivity for dilated loops of small bowel. For example, enteritis often causes mildly dilated loops of bowel with no functional obstruction. In the past, these dilated loops of bowel would have gone unrecognized on plain film. It is also important to recognize that CT often demonstrates small bowel to small bowel intussusceptions that are transient, physiologic, and require no intervention. Clinicians evaluating patients with abdominal pain should be aware of the oversensitivity of CT in identifying small bowel dilatation and include nonobstructive causes in the differential diagnosis.

What Is the Epidemiology of Large Bowel Obstruction?

LBO is an urgent situation which requires prompt diagnosis and intervention. The potential competency of the ileocecal valve creates a proximal point of relative obstruction and creates the potential for a closed loop if a distal obstruction develops. For that reason, perforation and ischemia are more common with LBO. The majority (60%) of LBO are caused by malignancy, notably colon cancer. Twenty percent of LBO are caused by diverticular stricture and abscess, and 5% are due to colonic volvulus. Adhesions seldom cause LBO and the principles of nonoperative management of SBO do not apply to LBO.

It is very important to make the distinction between mechanical LBO and acute colonic pseudo-obstruction (ACPO). ACPO is defined as acute colonic dilatation in the absence of obvious colonic disease or mechanic obstruction and is referred to as *Ogilvie's syndrome* or *adynamic colonic ileus*. ACPO most often affects the hospitalized or institutionalized patient with ongoing medical or surgical ailments. The pathophysiology is poorly understood but it is believed that alterations in the autonomic nervous system lead to impaired colonic motility and distention. The colonic distention usually is limited to the colon proximal to the splenic flexure. Although ACPO is often a benign disorder, complicated cases can be lethal. Uncomplicated ACPO has a mortality of 15% in the absence of perforation. This mortality is often attributed to the underlying illness in which the ACPO develops. Perforation of the colon increases the mortality to 40% and occurs in 3% of patients.(7) The risk of perforation increases as the cecal diameter exceeds 12 cm and the interval of colonic dilatation exceeds 48 h.(8) Early surgical consultation and aggressive medical management can mitigate the impact of ACPO.

Diverticular disease is common and has an age-dependent prevalence. Thirty percent of those afflicted with diverticulosis develop symptoms and a small percentage will present with a LBO. The etiologies include stricture formation from chronic diverticular colitis and extramural compression by diverticular abscess. Obstruction almost always occurs at the sigmoid, where diverticular disease is most common.

Colorectal cancer presents with a LBO in 8.9–34% of cases.(9, 10) Obstructing colorectal lesions often present with lymph node and distant metastasis and have a lower probability of complete resection. Despite complete resection, obstructing colon cancer has a lower long-term survival when compared to nonobstructing lesions. The 5-year survival with an obstructing colon cancer is 10–30%.(11) The literature has not clearly shown if the lower survival with obstructing lesions is secondary to staging, patient comorbidities, or more aggressive tumor biology. Overall, patients with obstructing lesions face higher hospital morbidity and mortality as well. Patients tend to be older and often present in metabolic disarray. Modern series report hospital mortality in the range of 10%. The rate of perforation with an obstructing colon cancer is 18% and the cecum can often be ischemic or necrotic secondary to distention.(12) Prompt surgical evaluation and intervention is necessary. The majority of obstructing lesions are located on the left side of the colon. There is particular predilection to the splenic flexure and sigmoid. Rectal lesions rarely present with obstruction, likely because of hematochezia. Right-sided lesions rarely obstruct because the enteric contents are liquid in the proximal colon. Obstructing right-sided lesions tend to present with a higher proportion of lymph node and distant metastases.(13) The management of obstructing colon cancer is challenging and partly dependent upon which side of the colon the obstructing tumor resides.

Volvulus of the colon is a rare disease in industrialized nations but significantly more common in the third world. It accounts for 5% of cases of LBO in the United States. The sigmoid colon is affected in 40–80% of cases. Cecal volvulus accounts for 10–50% of cases. Cecal volvulus can be divided into two groups. Ninety percent of cecal volvuli are axial ileocecal counterclockwise twists. Cecal bascule accounts for 10% of volvuli and it occurs when there is an upward rotation of cecum causing obstruction at the folded end. Splenic flexure and transverse colon volvulus are rare.

The majority of patients with colonic volvulus are elderly, and a significantly higher proportion of sigmoid volvulus occurs in the aged and institutionalized.(14) Nevertheless, it is important to recognize that colonic volvulus can occur at any age. In order for a colonic volvulus to occur, the patient must have a large and floppy segment of colon based on a narrow mesenteric pedicle. This allows for free rotation and obstruction. A colonic volvulus is an urgent situation requiring prompt intervention. The mortality for colonic volvulus is 14% and it escalates to 30–40% once necrosis occurs.

WHAT ARE THE CLINICAL FEATURES AND EVALUATION OF INTESTINAL OBSTRUCTION?

The initial evaluation of the patient with suspected intestinal obstruction starts with an accurate history and physical. The history should be directed toward two goals: identifying the etiology of the obstruction and determining the risk of bowel ischemia. The physical examination should also be directed toward quickly establishing the diagnosis of obstruction, screening for common etiologies, and determining the urgent need for surgical exploration. It is crucial not to miss abdominal wall hernias during the examination. Keep in mind that incisional hernias are often missed in obese patients.

Clinically, it is not difficult to diagnose intestinal obstruction. Most patients present with abdominal pain, bilious emesis, distention, and obstipation. The pain is colicky and dull in nature. The abdominal exam is notable for distention, hyperactive, and high-pitched bowel sounds and diffuse abdominal tenderness without peritoneal signs. There is variability in the findings based on the anatomic location and timing of the obstruction. For example, proximal obstructions may not have much distention. Early in the presentation, the emesis can be gastric in nature, but will eventually be bilious. Feculent emesis is a sign of a distal and chronic obstruction, likely located in the colon. Patients with LBO present with emesis as a late symptom and often present with dry heaves, severe pain, and distention. Despite this variability, the diagnosis is easily obtained. It is also not difficult to diagnose the patient with perforated bowel or severe intestinal ischemia. They appear ill and are often tachypneic, hypotensive, and tachycardic. In cases of perforation, the exam often demonstrates a rigid, board-like abdomen due to peritonitis. Ischemic patients present with severe abdominal pain out of proportion to the degree of peritonitis. The challenge lies in identifying patients with strangulated and reversible ischemic bowel who can avoid bowel resection or perforation with an expedited exploration.

It is important to recognize strangulation early because the morbidity and mortality of intestinal obstruction increases significantly once bowel infarction or perforation occurs. These patients have a protean presentation with a history and exam somewhere between a patient with a simple obstruction and a patient with frank perforation. A small study relying on clinical exams by senior surgeons revealed a sensitivity and specificity for strangulated bowel of 48% and 83%, respectively.(15) Patients with strangulation are often tachycardic and have ongoing pain. The abdominal exam may demonstrate focal abdominal tenderness and mild peritonitis. Unfortunately, the exam may also be underwhelming and falsely reassuring. This predicament has led some surgeons to argue for early operative treatment of complete bowel obstruction. The initial physical findings are not reliable in ruling out strangulation. Typically, these patients will have a progressive exam, and serial abdominal examinations should identify patients who are on the wrong trajectory and should proceed to operative intervention. The diagnostic accuracy and clinical impact of serial abdominal examinations by a surgeon on the outcome of patients with suspected bowel strangulation and complete SBO have not been studied. Therefore, adjuncts such as laboratory data and imaging are necessary to make an assessment and implement a treatment plan.

The laboratory work-up of patients suspected of having intestinal obstruction should include a complete blood count with differential, electrolytes, liver and pancreatic function test, and urinalysis. Patients suspected of having ischemic bowel should have an arterial blood gas and serum lactate level. Patients with a high WBC count, metabolic acidosis, and elevated lactate are likely to have intestinal ischemia and should be explored. Nevertheless, normal laboratory parameters do not exclude the possibility of strangulated bowel.

The ideal laboratory marker for intestinal ischemia does not exist. Experimentally, several laboratory factors have been associated with ischemic bowel. These include serum glutamate, tumor necrosis factor, and creatinine phosphokinase.(16) These markers are hampered by being specific but not sensitive. Polk and colleagues have recently

reported a small clinical series on the use of the cobalt–albumin binding assay (CABA).(17) They report an elevated CABA has 100% sensitivity, 86% specificity, and 93% accuracy in the diagnosis of bowel ischemia. Several groups have also reported value in the use of diagnostic paracentesis for the diagnosis of strangulated bowel. As will be discussed later, free peritoneal fluid is a frequent but not specific finding in CT evaluation of ischemic SBO.

Peritoneal fluid analysis for red blood cell (RBC) count and lactate has been shown to have high predictive value for strangulation.(18, 19) Ongoing research will determine if these laboratory tests will be integral parts of the work-up of patients with intestinal obstruction and finally provide an accurate preoperative marker of bowel ischemia.

> The case patient presents with classic history and physical exam findings of a SBO. His laboratory work-up reveals a mildly elevated WBC count, but the rest of the examination yields no indication for immediate operative intervention.

IMAGING

Radiographic investigation in the setting of acute intestinal obstruction plays a critical role in the creation of the diagnostic and therapeutic plan. Radiography can rule in or rule out the presence of bowel obstruction and provide anatomic localization and a baseline for later comparison. The best and most efficient imaging strategy is a topic of debate and physician preference. The correct radiographic intervention will be predicated by the clinical history, examination, and the differential diagnosis.

Imaging for Small Bowel Obstruction

The choice of imaging the small bowel for intestinal obstruction can be a difficult decision for the evaluating clinician. The diagnosis of SBO is based on an abnormal gas bowel pattern identified on imaging. The normal gas bowel pattern consists of the absence or presence of minimal bowel gas in less than four nondistended loops of small bowel. Air should be present in the large bowel, and the bowel diameter should not exceed 2.5 cm. A SBO is defined as dilated loops of small bowel (> 2.5 cm) with appropriate air–fluid levels in greater than three dilated loops of small bowel. The absence of air in the colon is indicative of a complete and severe obstruction.

Upright and supine plain films of the abdomen are the first image obtained in the diagnosis of SBO. Although shown to be diagnostic in only 45–60% cases and normal in 21% of proven SBO, a plain film in the right clinical setting confirms the diagnosis and obviates the need for further imaging.

Plain films have low sensitivity but high specificity for the need of urgent surgical intervention. Free air, pneumatosis intestinalis, and portal venous air are indications for exploration in the setting of a SBO. These findings are rare. The severity and thus the chances that nonoperative management will succeed is based on whether the SBO is partial or complete. A complete SBO has multiple dilated loops of small bowel with complete absence of air in the rectum. Some surgeons regard this finding as an indication for immediate operative management given the difficulty in clinically assessing strangulation of the bowel.

CT of all patients with suspected SBO seems to be routine in most emergency wards but CT is most useful in selected patients. Patients with a partial adhesive SBO with no clinical signs of perforation or ischemia, rarely benefit from CT scan. Furthermore, operative management should not be delayed for advanced imaging studies when clear indications for urgent operations are present (free air, pneumatosis, peritonitis or closed loop). CT scan is helpful in the patient with incongruent clinical, physical, laboratory, and imaging data. The main argument for the use of CT in all patients with bowel obstruction lies in the potential ability of CT to rule in or rule out strangulation and small bowel ischemia. But large studies supporting its application in this patient population do not exist. Nevertheless, a CT scan with no signs of ischemia is reassuring and gives the clinician confidence in pursuing nonoperative management in patients with a complete SBO.

The sensitivity and specificity of CT for the diagnosis of small bowel ischemia in the setting of obstruction are based on small, nonrandomized studies with high variability in the severity of bowel obstruction and differences in the criteria for radiographic diagnosis. Several radiographic findings have been associated with presumed bowel ischemia. In general, no individual sign of bowel ischemia is reliable enough to rule it out. The presence of ascites and mesenteric fluid seem to be the most sensitive signs of bowel ischemia. Decreased segmental bowel wall enhancement and thickening of the bowel are the most specific signs of ischemia. Specific mention has been made of the mesenteric swirl sign and small bowel feces signs as indicators of obstructive severity and possible volvulus. The swirl sign is poorly predictive of a volvulus and the small bowel feces sign does not imply severity of obstruction but is useful in localizing the point of obstruction.(20) The overall sensitivity for bowel ischemia ranges 52–93% and the specificity is 88–93%. The positive predictive value of CT is 80% and the negative predictive value is 95–99%.(21, 22) Signs of ischemia on a CT should warrant close examination of the patient and clinical data to ensure that nonoperative management is appropriate. The clinical benefits added by the potential early detection of ischemic signs by CT are unproven and largely speculative.

CT can be helpful in patient with no history of abdominal surgery or a history of malignancy. CT has the advantage of identifying extraluminal compression, hernias, and tumors. The sensitivity of CT for small bowel neoplasms is small but in the context of an obstruction, a mass is often identified. CT is also helpful in the patient with Crohn's disease because it can help in differentiating obstruction caused by phlegmon versus stricture. Metastatic recurrence and peritoneal carcinomatosis can often be identified on CT. The information gathered by CT on these patients often tailors the treatment plan.

With the advent of CT, the need and use of other advanced imaging modalities in the management of an acute small obstruction is rare. These modalities often require the presence of a radiologist to perform the study and are seldom available on an emergency basis. Small bowel follow-through is very sensitive for obstructive disease and provides mucosal detail not available on CT. Enteroclysis is a technique of intubation of the bowel and infusion contrast medium under pressure. It challenges the distentability of the bowel and exposes mild or subclinical obstruction. An enteroclysis showing rapid transit of contrast into the

colon safely excludes the diagnosis of SBO. These imaging studies are most useful in patients with chronic symptoms of obstruction not elucidated by CT scan.

> The patient's plain film imaging is consistent with a complete SBO. No hard signs of bowel gangrene or perforation are noted. Because the obstruction appears complete, a CT was obtained to estimate the risk of ischemic bowel. The CT confirms the diagnosis of complete SBO with a transition point in the right pelvis. Free fluid is noted but no specific signs of bowel ischemia are noted. The CT findings support a trial of nonoperative management for SBO.

Imaging for Large Bowel Obstruction

The management of LBO is largely dependent upon making the correct etiological diagnosis. The clinical history and exam are helpful in differentiating the source of obstruction, but imaging is the key to the diagnosis. It is of paramount importance to make the correct diagnosis and act accordingly since any LBO is potentially a closed loop obstruction if the ileocecal valve is patent.

The imaging work-up for LBO begins with a plain radiograph. The diagnosis LBO is based on a colonic diameter of 6 cm or greater and air–fluid levels within the colon. Small bowel dilatation can be seen if the ileocecal valve is not competent. Free air, pneumatosis coli, and portal venous air are immediate indications for operative intervention. The risk for perforation increases as the diameter of the cecum increases beyond 12 cm.(8) The etiology of LBO and distinction from colonic pseudo-obstruction can be difficult to make with a plain radiograph, and further imaging is often needed. Nevertheless, there are several types of LBO that can be diagnosed and triaged accurately by plain film.

Colonic volvulus can be reliably diagnosed with a plain film in 65–89 % of patients.(23, 24) Reported plain film signs of colonic volvulus include dilated, ahaustral colon with absence of rectal air, "coffee bean sign," and inverted U sign.(25) In sigmoid volvulus, the limbs of the inverted U point toward the pelvis and the dilated colon can lie either on the left or right. The northern exposure sign, with the sigmoid colon rising above the transverse colon is described.(25) Cecal volvulus has similar signs but the limbs of the inverted U point toward the right lower quadrant (RLQ).

Contrast enema is considered the imaging gold standard for LBO. It accurately diagnoses and localizes the source of obstruction. Chapman reports a sensitivity of 96% and specificity of 98%.(26) Colonic volvulus is diagnosed by the classic, bird's beak appearance of the obstruction. Colonic obstruction by a cancer produces the pathognomonic apple core stricture. Diverticular strictures tend to be much longer than malignant colon cancer strictures. A careful contrast enema can also distinguish ACPO from mechanical obstruction.(27)

CT is gaining popularity in the diagnosis of LBO. CT provides anatomical and etiological information. Given the higher incidence of malignant obstruction of the large bowel, CT has the advantage of providing staging information. CT can help to differentiate a sigmoid malignancy from a diverticular stricture but colonoscopy with biopsy is needed to confirm the diagnosis. The

diagnosis of colonic volvulus is easily confirmed with CT, and the differentiation between sigmoid and cecal volvulus is excellent. Given the accessibility and ease of interpretation, CT may be the study of choice if the plain film is not sufficient to make the diagnosis and initiate a treatment strategy.

Summary

Imaging for intestinal obstruction remains an area of controversy. Although CT is the study of choice for the workup of intestinal obstruction, there are no data confirming morbidity and mortality benefit from its use. The plain radiograph is inexpensive and easy to obtain. It will often identify clear indications for operative management and obviate the need for further imaging. If a concrete management plan cannot be formulated based on the clinical data and plain film imaging, CT is the next study of choice. The availability of CT and its ease of interpretation make it superior to a contrast study for the work up of an intestinal obstruction in the urgent setting.

WHAT ARE THE TREATMENT ALGORITHMS FOR THE MANAGEMENT OF INTESTINAL OBSTRUCTION?

The decision-making process in the treatment of acute intestinal obstruction is challenging. The indications for operative management in the stable patient are unclear and there are many different operative strategies once the decision to intervene is made. The initial management of all the patients with intestinal obstruction involves contemporaneous assessment and resuscitation. Patients with intestinal obstruction are volume-depleted. Electrolyte imbalances are common. Patients with intestinal ischemia are often in profound shock. Large bore access and fluid resuscitation should be instituted immediately.

All patients with intestinal obstruction benefit from nasogastric decompression. Even patients with evidence of a LBO and no small bowel dilation will benefit from aspiration of swallowed air. Placement of a NGT should not be delayed for imaging confirmation. The diagnosis should be made on clinical grounds, and delay in aspiration of intestinal contents may place the patient at risk for aspiration. Antibiotic coverage should be reserved for patients with evidence of active ischemia or perforation.

The clinical, laboratory, and imaging work-up should be prompt and efficient. The key to the successful management of intestinal obstruction depends on making the correct diagnosis early. Miscalculations in assessing the etiology of obstruction or the risk of strangulation often lead to delays in diagnosis and poor patient outcome.

Management of Small Bowel Obstruction

Regardless of the etiology of obstruction, most patients with a high probability of intestinal ischemia, closed loop obstruction, perforation, or hemodynamic instability should proceed immediately to the operating room for exploration. The management of stable patients with SBO is dictated by the specific etiology suspected of causing the obstruction.

Adhesive Small Bowel Obstruction

The management of adhesive SBO is one of the most controversial areas in acute intestinal surgery. The decision making is

complicated by the fact that up to 80% of patients will resolve with nonoperative management but the sensitivity of clinical, laboratory, and imaging for early intestinal ischemia is poor. Furthermore, the morbidity and mortality of developing intestinal gangrene or perforation is much worse than if ischemic bowel is reperfused promptly. This creates a situation in which most patients will do well without an operation, but the cost of not operating on the patient with early signs of ischemia can be high.

The first step in management of an adhesive SBO is to decide whether or not the patient must go to the operating room. The combination of clinical history, abdominal exam, laboratory and imaging data, and the experience of the clinician will determine this assessment. Patients with a low risk of ischemia are appropriate for nonoperative management. Partial SBO with a reassuring exam and complete SBO with a reassuring exam and a CT scan with no signs of ischemia can be managed nonoperatively.

Nonoperative management of adhesive SBO involves volume resuscitation, bowel rest, bowel decompression, and serial abdominal, radiographic, and laboratory examinations. Around 60–80% of patients selected for nonoperative management will resolve and obviate the need for an operation. Patients who demonstrate a worsening examination should be explored as well as patients who fail to resolve after a reasonable period of observation. The exact timing at which a patient is deemed a failure of operative management is debated. A retrospective review of nonoperative management by Cox revealed that 88% of patients who will resolve will do so in 48 h and the remaining resolved in 72 h.(28) All patients with persistent obstruction beyond 72 h required an operation. Others have advocated longer waiting periods. Seror demonstrated safety in observing patients up to 5 days.(29) The median time to resolution of symptoms was 24 h and no patient resolved after 5 days of observation. This prolonged observation did not result in increased incidence of strangulation. Shih extended the observation period up to 14 days.(30) Clearly, the length of observation is an arbitrary number determined by how long one wants to observe a patient. Most patients with strangulated bowel assigned to nonoperative management will declare themselves within 24 h. Beyond that time, failure of nonoperative management is due to persistent obstruction and not ischemia. Therefore, the appropriate length of nonoperative management is dependent upon the risk–benefit ratio of a prolonged hospitalization and lack of enteral nutrition versus the morbidity of an exploratory laparotomy. For most patients with adhesive SBO and no signs of strangulation, 48–72 h seems appropriate.

Patients with early postoperative SBO illustrate an extreme of this risk–benefit ratio. An early postoperative SBO occurs within the first 30 days after surgery. It is differentiated from an ileus by the fact that patients have regained bowel function after the operation and then develop signs and symptoms of obstruction. The majority of early postoperative bowel obstructions are caused by adhesions, but an exhaustive process to rule out other etiologies should be undertaken. Several observational studies have demonstrated that most patients with an adhesive etiology never develop intestinal ischemia and it may take 1–2 weeks for the obstruction to resolve.(31, 32) Pickelman demonstrated that 70% resolve within 1 week, 96% within 2 weeks, and 100% by

17 days. None of the patients which required exploration based on clinical suspicion of ischemia had strangulation or required bowel resection. Bowel ischemia is rare in this group and the increased risk of exploration in the setting of dense adhesions favors a prolonged period of nonoperative management.

Patients with early postoperative bowel obstruction following Roux-en-Y gastric bypass represent the other extreme of this risk–benefit ratio. The incidence of strangulation and closed loop obstruction in patients with postoperative bowel obstruction after gastric bypass can be as high as 40%. That risk combined with the difficulty in the abdominal examination of the morbidly obese, favors immediate exploration or a very short course of nonoperative management.

> The case patient was managed with appropriate nonoperative management. He was admitted to the hospital and resuscitated. A NGT was placed and the output monitored. Serial abdominal examinations did not demonstrate progression to bowel ischemia. After 48 h of observation with no return of bowel function the patient was deemed a failure of nonoperative management.

Several components of nonoperative management of adhesive SBO are still unsettled. The use of a long intestinal tube for decompression of the small bowel has been advocated by many. The advantage of long intestinal tubes is that the tube is advanced to the point of obstruction and the bowel under maximal tension is quickly decompressed. Several studies have reported resolution rates of 60–80% (33, 34) and as high as 90% in modern series. (35) There is one randomized trial in the use of short NGTs versus long nasoenteric tubes in 55 patients with SBO.(36) In this small study, the success rate of conservative management was 70% in the long tube group and 56% with NGT. This difference was not statistically significant. Therefore, the role of long intestinal tubes in the management of SBO remains unclear. The placement on a long tube requires more time and often the use of endoscopy or fluoroscopy. Most centers opt to use NGTs for the management of SBO. A properly powered multi-institutional trial is necessary to resolve this issue.

Gastrografin has emerged as an important factor in the management and treatment of adhesive SBO. Evidence of passage of Gastrografin into the large bowel 4–24 h after it is administered, predicts with high-accuracy patients with a partial SBO and a high chance of successful nonoperative management.(37, 38) A pooled analysis of several prospective trials demonstrates 97% sensitivity and 96% specificity for predicting successful nonoperative management.(39) The data are unclear as to what the correct action should be if contrast does not pass into the colon. Patients are arbitrarily explored if the contrast does not pass within 24 h, but it is unclear if these patients would have resolved with a few more days of conservative management. The passage of contrast into the colon predicts resolution but the lack of passage returns the decision making back to the risk–benefit ratio of ongoing observation versus exploration.

A therapeutic benefit in the form of faster resolution of partial SBO and less need for surgical intervention has been attributed to the use of Gastrografin. The meta-analysis by Abbas

concluded that Gastrograffin does not reduce the need for operative intervention but does decrease the time to return of bowel function and length of stay in patients with passage of contrast into the colon.(39) This added benefit has to be tempered against the potential side effects of Gastrografin, mainly severe pneumonitis from aspiration. The use of Gastrografin in clinical trials has shown to be safe. Gastrografin should be part of the nonoperative management of SBO, not only for its predictive value but also for the potential decrease in length of stay in patients with partial SBO.

Once the decision is made to operate on adhesive SBO, the operative management of SBO is relatively simple. Most patients explored for strangulation have a single adhesive band or internal hernia with volvulus. Identification of the transition point and lysis of the adhesion will resolve the obstruction. Patients with matted adhesion require extensive lysis of adhesion until a transition point is identified and the obstruction relieved. Necrotic bowel should be resected and a primary anastomosis should be created. Loops with reversible ischemia should be carefully evaluated for viability and if any doubt remains at the end of the operation, a second-look laparotomy should be planned.

Several studies have documented lower recurrence rates of patients treated with operative interventions as compared to those patients managed nonoperatively.(4, 40, 41) Because of the lack of randomization, there is obvious selection bias toward patients with single adhesions and hernias. These patients may inherently have a lower recurrence rate than patients with matted adhesions that typically cause partial SBO.(5) A more aggressive surgical posture toward adhesive SBO with the goal of lowering the recurrence rate should not be based on these studies.

The use of laparoscopic exploration and lysis of adhesion has increased in the management of SBO. Most descriptions are small retrospective case series. A pooled analysis of 1,061 cases including 83.2% for adhesive SBO demonstrated a success rate of 66% and conversion rate of 34%.(42) There was a high rate of recognized enterotomies (6.5%) and unrecognized enterotomies (1.3%). Laparoscopy is reported to have a lower adhesion formation rate but, data on the long-term recurrence rate after laparoscopic versus open lysis of adhesions do not exist. Performing a laparoscopy in the context of adhesions and dilated bowel can be quite difficult and should only be done by those with expertise in laparoscopic surgery.

> Failure of nonoperative management mandates surgical exploration. For this patient, 48 h of observation was selected. He was explored laparoscopically, and a single adhesive band was identified as the culprit of the SBO. There was no evidence of bowel ischemia. Therefore, the band was lysed without any resection of bowel. The patient developed an early postoperative SBO. A CT was consistent with an adhesive etiology. No abscess, volvulus, or laparoscopic port site hernia was noted. Nonoperative management was selected. Because the diagnosis was an early postoperative SBO, the observation period was longer. The patient resolved after 7 days and was subsequently discharged home on a regular diet.

Hernias

The management of strangulated hernia and SBO can be challenging. The highest incidence of bowel ischemia in the setting of SBO occurs in patients with strangulated hernias. Therefore, there should be a low threshold for operative management. Most patients with evidence of a strangulated and incarcerated hernia should proceed to the operating room for repair. Alternatively, the hernia can be reduced at the bedside with or without conscious sedation. The advantage of exploration is the immediate assessment of the viability of the threatened segment of bowel. A definitive small bowel resection can be performed if the intestine is not viable. Bedside reduction of a strangulated hernia requires a period of hospital observation to ensure that the ischemic bowel is not permanently injured or perforated. The reliability of clinical exam for ischemia is poor and therefore, some patients with gangrenous bowel will have a delay in diagnosis and worse outcome. Bedside reduction offers the advantage of delaying the repair until a time when bowel distention and bacterial translocation associated with strangulation has resolved. This increases the treatment options available for the management of the hernia defect.

Controversy exists regarding the use of prosthetic material for repair of hernias associated with strangulated bowel. The risk of chronic prosthetic infection is speculated to be higher in the setting of strangulation. Most surgeons would not use a permanent mesh in the setting of perforation but some believe that it is acceptable in the setting of strangulation with no perforation. (43, 44) Many of these hernias can be closed primarily and obviate the risk of mesh infection. Furthermore, the use of biological prosthetic material may mitigate the risk of prosthetic infection in the setting of strangulated hernia, but the long-term hernia recurrence rates appear high.(45)

Malignant Small Bowel Obstruction

Surgical management of malignant SBO is challenging. Most patients present with metastatic or locally advanced disease, making operative correction complicated. Nevertheless, most patients with isolated metastatic lesions and primary small bowel tumors benefit from resection for the relief of obstruction. It is becoming clear that operative intervention in the setting of diffuse peritoneal carcinomatosis is associated with poor symptomatic relief and high morbidity and mortality.(46) These patients often have multifocal areas of partial obstruction. The bowel is essentially fixed to multiple tumor implants, is unable to twist and rarely develops ischemia. With a low risk of ischemia and high recurrence rate, operative intervention in the setting of peritoneal carcinomatosis should be avoided. Palliation of symptoms and maximizing quality of life are the treatment goals. The use of percutaneous gastrostomy offers a minimally invasive approach to palliate patients with recurrent obstructions. The gastrostomy allows for intermittent venting and drainage. In patients with peritoneal carcinomatosis secondary to gynecological cancer, percutaneous gastrostomy has been shown to resolve symptoms and allows the consumption of liquid or soft food.(47, 48) These patients can be discharged from the hospital to receive end of life care at home or a hospice facility.

MANAGEMENT OF LARGE BOWEL OBSTRUCTION

Malignant Large Bowel Obstruction

The management of malignant LBO requires a rapid assessment of the patient and localization of the obstructing lesion. Right-sided lesions should proceed to the operating room promptly. Right colectomy with ileocolostomy is appropriate in most situations and it is accepted in the literature. More than 90% of obstructing right-sided colon cancers can be managed with resection and primary anastomosis.(10, 13) Patients with high vasopressor requirement and hemodynamic instability should have an ileostomy created. Rarely, ileocolic bypass without resection of the primary lesion is necessary due to extensive local invasion.

The operative management of left-sided colonic lesions is controversial. The controversy arises from the higher anastomotic leak rate associated with colocolostomy. Further exacerbating the concern is creation of an anastomosis with distended, unprepped colon in the context of dehydration and advanced malignant disease. There are three generalized approaches to the management obstructing colon and recently, a fourth strategy involving stenting has emerged as a viable treatment option. In the distant past, a three-staged approach was advocated. This approach consisted of creating a diverting colostomy, followed by resection and anastomosis and finally stoma closure. It has been largely abandoned due to the higher morbidity associated with three operative interventions, longer length of stay and a high permanent colostomy rate. On the other end of the spectrum is resection with primary anastomosis. The intermediate position is resection with creation of an end colostomy and Hartman's pouch. Certainly, this is the strategy of choice in patients in shock and gross peritoneal soilage. For stable patients, the morbidity from a leak from a primary anastomosis must be balanced against the morbidity of second operation to reverse the stoma, quality of life with the stoma, and the well known fact that 40–60% of "temporary" stomas turn out to be permanent.

Several strategies are available to perform a resection of the tumor and achieve bowel continuity. First, one can perform a subtotal colectomy with ileocolic/rectal anastomosis. This strategy offers the advantage of creating what is believed to be a safer ileorectal anastomosis and removes potential synchronous lesions.(49) However, removing the majority of the colon leads to frequency and urgency of stools. The frequency of bowel movements associated with subtotal colectomy generally resolves after several months.(50) The second strategy is to perform a segmental colonic resection with on-table colonic lavage. These two strategies were tested in a randomized control trial. The SCOTIA trial randomized 91 patients to either subtotal colectomy with ileocolostomy versus segmental resection colocolostomy with on-table colonic lavage.(51) The study was small and not powered to demonstrate small differences in outcome. The anastomotic leak rate, hospital mortality, and length of stay were similar between both groups. The only demonstrable difference was a higher number of bowel movements in the subtotal colectomy group. For that reason, several groups advocate segmental resection and primary anastomosis.(52, 53) Several other authors argue that colonic irrigation has no added benefit.(54–56) A randomized trial comparing colonic irrigation with manual decompression demonstrated no difference in outcome between the two procedures but longer operative time with colonic irrigation.(56) A fair assessment of the data yields no conclusive

recommendations. If conditions are favorable, segmental resection with primary colocolostomy or subtotal colectomy with ileocolostomy are probably equivalent procedures in the long term. Intraoperative findings may favor one procedure versus the other.

The controversy in the management of left-sided malignant obstruction has been further complicated by the emergence of expandable stent as a "bridge to surgery". Stenting decompresses the colon and allows for volume and metabolic resuscitation. Furthermore, a mechanical colon cleansing can be performed. This converts an emergency dirty operation into a semielective situation with prepped and decompressed bowel. Presumably, this strategy should improve survival and morbidity and possibly decrease the rate of temporary stomas. In the absence of peritonitis, hemodynamic instability or perforation, the placement of a metallic stenting may be the appropriate first intervention in patients with left-sided obstruction. Success rates of 90% have been reported.(57, 58) Stent migration occurs in 10% and is more likely in the hepatic and splenic flexures and in the lower rectum. The rate of perforation is 3% and the reobstruction rate is 7–10%. A historical case matched study of the use of stenting as a bridge to one-stage resection demonstrated lower wound infection and anastomotic leak rate and equivalent long-term survival.(59) A randomized control trial of self-expanding colonic stenting as a bridge to surgery versus emergency operative management is accruing patients.(60) The primary end point is quality of life and secondary endpoints are morbidity, survival, and cost. Right-sided lesions can be decompressed by colonic stenting but given the high rate of primary anastomosis, there seems to be little benefit in the use of stenting as a bridge to surgery in right-sided lesions.(61)

Patients with isolated and extensive liver metastasis have reasonable survival and should undergo removal of the primary tumor and either temporary colostomy or primary anastomosis. Patients with peritoneal carcinomatosis and colonic obstruction tend to have poor long-term outcome. Several authors have published good outcomes with the use of self-expanding stents for the palliation of unresectable malignant colonic obstruction.(62–64) Palliative stenting is associated with relief of obstruction, shorter hospital stay, and quicker time to initiation of chemotherapy.

Colonic Volvulus

The management of colonic volvulus is dependent upon the clinical presentation and location of the volvulus. The main goal of treatment is rapid detorsion of the colon. Sigmoid volvulus, in the absence of perforation or necrosis, is managed by endoscopic reduction followed by elective operative intervention when the patient is resuscitated. The management of acute cecal and transverse colonic volvulus is urgent operative detorsion.

Sigmoid volvulus was managed by urgent operation until Bruusgaard published a successful detorsion rate of 86% after decompression with a proctoscope and rectal tube. Others have reported equivalent success rates, and nonoperative decompression is the preferred first step in the management of sigmoid volvulus. Endoscopy has the advantage of not only being effective, but also allows direct inspection of the mucosa. Endoscopic reduction can be performed with rigid or flexible sigmoid scope. Colonoscopy has the advantage of evaluating the entire colon. Barium and saline enemas can be used for reduction but are prone to perforation and

early recurrence and give no information of the perfusion status of the colon. The use of contrast studies instead of endoscopy may be associated with a higher morbidity and mortality rate. (65) Most endoscopists leave a rectal tube in place after detorsion. Endoscopic reduction is a temporary measure. Recurrence rates are as high as 70% and can occur in days to weeks after detorsion. Nevertheless, endoscopic detorsion stabilizes an emergent situation and allows for resuscitation of the patient.

Failure of nonoperative detorsion requires urgent operative exploration. Unstable patients with gangrenous colon should undergo sigmoid resection and subtotal colectomy with end ileostomy and Hartman's pouch. Alternatively, several groups have demonstrated good outcomes in selected patients with gangrenous colon managed by primary resection and anastomosis, with or without on-table colonic lavage.(65, 66) They report mortality rates comparable to series managed by resection and colostomy. The surgeon should decide the operative strategy based on experience and physiological status of the patient.

The goal of treatment for patients successfully managed by endoscopic detorsion is long-term prevention of recurrence. The high recurrence rate in the days to weeks after endoscopic reduction suggests that most patients with an acceptable risk profile should undergo a definitive operative intervention. A 2-day interval between endoscopic and definitive operative intervention has been suggested (67), but most surgeons choose to perform the operation toward the end of the same hospital admission. The operative options include manual detorsion, mesosigmoidpexy, extraperitonalization of the sigmoid, and resection and primary anastomosis. Long-term recurrence rate data are scarce but recurrences have been reported with all approaches, including sigmoidectomy.(68) Some advocate subtotal colectomy primary anastomosis as the operative intervention with the lowest recurrence rate in patient with megacolon.(68–70) Two groups have reported a zero 5-year recurrence rate with the use of extraperitonealization of the sigmoid.(71, 72) No consensus data exist and it is fair to say that the long-term recurrence of sigmoid volvulus after operative intervention is unknown.

In contrast to sigmoid volvulus, endoscopic decompression is rarely successful for the other anatomic locations of colonic volvulus. The initial management of these disorders is operative detorsion and resection. There should be no delay between diagnosis and surgical exploration. The surgical options are dependent upon the operative finding. Necrotic volvulus should be resected and in most circumstances a primary anastomosis can be performed. If the colon is viable, treatment options depend on the anatomic location. For the most part, resection and primary anastomosis is recommended for transverse, descending, and splenic flexure volvulus. Several options have been described for cecal volvulus. These include simple detorsion, cecopexy, cecostomy, and resection with primary anastomosis.(73) Simple detorsion is not recommended because of recurrence rates as high as 75%.(73) Cecopexy has a long-term recurrence rate of 0–27%. Cecostomy has a recurrence rate of 0–33% but seven of eight studies document no long-term recurrences. There have been reports of leaks and peritonitis with cecostomy and the morbidity may be higher than for resection or cecopexy. There are no reported cases of recurrence after resection, but overall mortality seems to

be higher in the resection groups (0–18%). It is important to note that these series include patients with gangrene. There are no randomized data to guide treatment so the surgeon must balance the risk of recurrence versus the potential of higher morbidity and mortality with resection.

Acute Colonic Pseudo-obstruction

The management of ACPO is essentially nonoperative. Patients with ACPO need volume resuscitation and correction of electrolyte imbalances as these may be contributing to the paralytic ileus. It is helpful to discontinue medications that impair gut motility such as, narcotics, anticholinergics, and calcium channel blockers. Nasograstric decompression and NPO status will minimize the amount of swallowed air reaching the colon. A rectal tube and serial rectal exams may facilitate the passage of flatus. Ambulation should be encouraged. It is important to follow the patient with serial abdominal exams focusing on the degree of distention and peritoneal signs. Daily abdominal plain films are useful to monitor the diameter of the cecum. For most patients, conservative management will lead to symptoms resolution.

The risk of perforation and bowel ischemia is low with ACPO. (74) The risk increases as the diameter of the cecum extends beyond 12 cm and with longer duration of distention. Therefore, patients with a dilated cecum and symptoms of failure to resolve after several days of conservative treatment should be managed with more aggressive measures. Pharmacologic interventions are helpful in the management of ACPO. Mild prokinetic agents like Erythromycin and enemas may be helpful, but concrete evidence of efficacy is not available.

Neostigmine is a potent acetylcholinesterase inhibitor which indirectly enhances colonic motility by increasing parasympathetic tone. A randomized controlled trial of patients with ACPO with cecal diameter of > 10 cm and no response to conservative management after 24 h revealed a 91% response rate to IV Neostigmine.(75) The response occurs within minutes and the recurrence rate was 11%. The incidence of symptomatic bradycardia was 10%. Several nonrandomized, prospective cases series document similar results. Mehta demonstrated that Neostigmine has better efficacy when electrolyte abnormalities are corrected. (76) Neostigmine is relatively inexpensive and should be the first treatment options for patients with ACPO not responding to conservative management. It is crucial to exclude mechanical obstruction prior to administration of Neostigmine. A standard imaging study has not been defined but water-soluble contrast enema or CT should suffice. Caution should be taken in administering Neostigmine to patients with extensive cardiac disease, bradycardia, or heart block. It should be done in a care unit able to manage the acute onset of bradycardia and hypotension.

Decompressive colonoscopy is indicated in patients who fail or have contraindications to Neostigmine. This includes patients for whom obstruction cannot be ruled out. The estimated success rate of decompressive colonoscopy is 69% (74) and is improved by the placement of decompressive rectal tube after decompression.(77) The rate of perforation is 3% and the need of repeat endoscopic decompression is 18%. The use of percutaneous decompressive cecostomy has been reported for high-risk patients.(78)

Surgery is reserved for patients with perforation, ischemia, toxic megacolon, or those who fail all other interventions. The operation usually performed is a subtotal colectomy with end ileostomy and Hartman's pouch. In the absence of ischemia or perforation, cecostomy has a high success rate. Colonic resection with colostomy or primary anastomosis is indicated in patients with ischemia or perforation. The mortality for patients undergoing surgical intervention for ACPO is 6%.(7)

Evidence Basis for Acute Intestinal Obstruction

There are no randomized controlled trials to support any aspect of this topic.

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60 Anastomotic leak and postoperative abscess

Peter A Pappas and Ernest FJ Block

A 30-year-old man with Crohn's disease is admitted with high-grade small bowel obstruction and undergoes a distal small bowel resection with primary anastomosis. Postoperatively, he develops a small bowel ileus and fever. On postoperative day 6, a Computed tomography (CT) scan of the abdomen and pelvis reveals a pelvic abscess. The patient returns to the operating room and undergoes resection and re-anastomosis for a small bowel anastomotic disruption along with drainage of a contiguous pelvic abscess.

WHAT ARE THE INCIDENCES, CAUSES, AND RISK FACTORS FOR ANASTOMOTIC DISRUPTIONS?

Anastomotic leaks are one of the most serious of all adverse events involving surgery of the gastrointestinal tract. While technical issues are often foremost in a surgeon's mind when confronted with this complication, multiple variables have been investigated as potential risk factors predisposing patients to anastomotic disruptions.(1) The literature is thus extensive and Tables 60.1 and 60.2 are designed to serve as a guide to the key references.

The incidence of anastomotic disruption varies widely in the literature.(2) The majority of studies report rates of leak for both small bowel and colonic anastomosis in the range of 1.0–4.3%. (1) In a review of 1,223 patients undergoing resection and anastomosis for all etiologies, Hyman reported a leak rate of 2.7%. (2) In a comprehensive retrospective review, Pickleman and colleagues delineated leak rates based on anatomic location. Out of 798 enterectomies reviewed, a leak rate of 1.1% was identified. For 1,217 partial colectomies with primary anastomosis, anastomotic disruption occurred in 1.7% of patients. Out of 234 patients with subtotal colectomy, the leak rate was 3%, including both emergent and elective procedures.

In terms of technique, three basic principles must be adhered: preservation of an adequate blood supply, precise tissue approximation, and lack of tension. The key underlying principle is that while the surgeon mechanically restores gastrointestinal integrity by use of suture or staple, it is subsequent tissue healing that establishes the ultimate integrity of the anastomosis. For healing to occur, adequate blood supply and accurate approximation are paramount.

In a multivariate analysis of 764 patients with an anastomotic leak rate of 3.4%, Golub identified six factors as significant predictive variables. These consisted of serum albumin levels less than 3.0 g/L, preoperative presence of peritonitis or bowel obstruction, along with use of corticosteroids, chronic obstructive pulmonary disease, and perioperative transfusion of greater than two units of packed red blood cells.(3) Colonic and small intestinal anastomoses had similar leak rates and no difference was noted between sutured versus stapled anastomosis.(3) In the colorectal literature, low-rectal anastomoses are held to have a higher leak rate overall, ranging up to 15%.(4)

Perioperative transfusion has been shown to be a particularly significant risk factor, with data extending back some 30 years. (1, 3) Golub noted a 14.3% leak rate for transfused patients versus 2.9% in nontransfused patients. The effect of perioperative transfusion was independent of intraoperative hypotension, estimated blood loss, or preoperative hematocrit.(3)

For most procedures, gender, age, and obesity do not appear to play a role (1, 3) and no benefit has been demonstrated from preoperative weight loss.(1) Male gender has been shown to be an independent risk factor following low anterior resection for rectal carcinoma, as well as preoperative radiation.(5) Patients with diabetes and hypertension have also been noted in some studies to have higher leak rates. Evidence also exists for smoking and a history of corticosteroid use to increase the risk of leak, particularly with regards to colonic anastomosis.(4)

Anastomotic leaks are of particular concern in colon and rectal surgery, especially with the growing acceptance of sphincter-preserving procedures for low rectal cancer. The incidence of anastomotic leak following low anterior resection ranges from 2 to 17%, with a mortality of 50% in the presence of generalized peritonitis and sepsis.(6) A traditional approach to prevention of anastomotic leak in colon and rectal surgery has been the creation of proximal defunctionalizing stomas. Dehni and colleagues compared anastomotic leak rates in patients who had undergone colonic–pouch–anal anastomoses and low colorectal anastomoses for rectal cancers lying between 6 and 11 cm from the anal verge. All patients with a colonic–pouch–anal anastomosis were given a defunctionalized stoma. Of the 136 patients receiving a low colorectal anastomosis, 30 were defunctionalized and 106 were not. For pouch–anal reconstructions, the anastomotic leak rate was 4.9% and that of defunctionalized colorectal anastomoses 6.7%. This compared favorably to patients with low colorectal anastomoses that were not defunctionalized. They demonstrated a leak rate of 17% with a significantly greater chance of peritonitis and unscheduled reoperation.(6)

Proper surgical management of Crohn's disease remains an ongoing challenge. Intestinal anastomoses in the setting of Crohn's disease are generally held to be at greater risk of anastomotic leak and septic complications postoperatively.(7) Recently, data have appeared demonstrating that both technique and orientation of bowel anastomosis may play a significant role in prevention of anastomotic leaks. Resegotti and colleagues have reported on a series of 122 consecutive Crohn's patients having undergone elective ileocecal or ileocolonic resections with an ileocolonic anastomosis. Fifty-five patients underwent a handsewn end-to-end anastomosis while 71 underwent stapled side-to-side anastomoses. The handsewn group was found to have a leak rate of 14.1% with 1.4% mortality, while stapled anastomoses demonstrated a 2%

Table 60.1 Quick Guide to References.

Author	Reference No.	Study Type	Grade
Pickleman J et al.	1	Retrospective chart review 2,842 patients	1B
Hyman N et al.	2	Prospective observational study 1,223 patients	1B
Golub R et al.	3	Retrospective multivariate analysis 764 patients	1B
Hedrick TL et al.	4	Retrospective chart review of 27 patients	2A
Matthiessen P et al.	5	Retrospective review of 432 patients	1B
Dehni N et al.	6	Retrospective review of prospective data on 258 consecutive patients	1C
Resegotti A et al.	7	Retrospective review of prospective data on 122 consecutive patients	1C
Simillis C et al.	8	Meta-analysis of eight studies: 2 prospective, randomized and controlled, 1 prospective, nonrandomized, 5 nonrandomized retrospective	1C
Behrman SW et al.	9	Retrospective review of 171 patients	1C
Nair A et al.	10	Retrospective review of prospective data on 70 patients	2A
Nelson R et al.	11	Meta-analysis of 33 studies with 5,240 patients	1B
Ballesta C et al.	12	Retrospective study of 1,200 patients	1B
Madan AK et al.	13	Retrospective review of 300 patients	1C
Demaria EJ et al.	14	Prospective study of 281 patients	2A
Frileux P et al.	15	Review article, expert opinion	
Gonzalez R et al.	16	Prospective study of 3,018 patients	1A
Upponi S et al.	17	Prospective study of 52 patients	2A
Sciarretta G et al.	18	Prospective study with 103 cases and 52 controls	2A
Norwood SH et al.	19	Retrospective review of 53 patients	2B
Power N et al.	20	Prospective blinded controlled study of 73 patients with 26 controls	2A
Nicksa GA et al.	21	Retrospective review of 36 patients	2B
Lucey BC et al.	22	Case report, expert opinion	
Solomkin JS et al.	23	Evidence-based guidelines	
Dellinger RP et al.	24	Evidence-based guidelines	
Calicis B et al.	25	Retrospective analysis of prospectively gathered data on 21 consecutive patients	2B
(26) Tay GS et al.	26	Retrospective study of 100 consecutive patients	2A

leak rate and no mortalities. By univariate analysis, anastomotic configuration was held to be the only variable affecting leak rate.(8)

Similar findings were demonstrated in a meta-analysis evaluating anastomotic configurations following resection in Crohn's patients. Simillis and colleagues evaluated eight separate studies: three prospective and five retrospective. Similar to Dehni's findings, end-to-end anastomosis were held to have higher leak rates than side-to-side configurations while there was no significant difference in perianastomotic recurrence between the two configurations.(9)

Trauma presents a unique set of challenges and risks. In a review of 171 patients undergoing 222 enterorrhaphies or resections with anastomosis, Behrman demonstrated an overall leak rate of 5% with a 2.3% rate for anastomoses. Leak was related to a higher injury severity score and need for higher volumes of fluid and blood for resuscitation. Small bowel anastomotic leak also occurred in each of three patients who developed abdominal compartment syndrome.(9) Intraoperative hypotension, hypoalbuminemia, and hyponatremia are also potential risk factors.(10)

One long-held practice increasingly viewed as of little value is routine use of nasogastric (NG) tube decompression. Nelson performed a meta-analysis of 33 randomized studies in the Cochrane database involving 5,240 patients who had undergone some form of gastrointestinal surgery. Of these, 2,628 underwent routine NG decompression and 2,612 had either no NG tube or selective use. Nelson demonstrated no difference in anastomotic leak rates between the two groups along with a later return of bowel function and increased pulmonary complications in those patients with routine NG tube use.(11)

Beyond technical considerations, there is a myriad of events and patient characteristics that may increase the risk for anastomotic leak. The fundamental principle is that an environment must exist for adequate tissue healing. Thus, risk factors should be seen in the context of impairing either adequate tissue perfusion/oxygenation or the process of wound healing itself.

WHAT ARE THE POTENTIAL CHALLENGES IN PRESENTATION AND DIAGNOSIS?

Diagnosis of anastomotic leak can be a significant challenge. Pickleman demonstrated an average time for diagnosis of a leak as 7.1–8.8 days postoperatively for small bowel and colonic anastomoses.(1) Anastomotic leaks have been shown to present as late as 38 days after surgery, mandating close follow-up in the outpatient setting.(2)

One of the most challenging anastomotic leak to identify is that associated with gastric bypass. Ballesta and colleagues undertook a retrospective review of 1,200 patients who had undergone laparoscopic roux-en-y gastric bypass. Postoperative care included routine

Table 60.2 References and Grade by Subject.

Incidence	Reference	Grade
Small bowel	1, 2, 3	1B
Colonic	1, 3	1B
Low-rectal	4	2A
Risk factors		
Transfusion	1, 3	1B
Age, gender	1, 3, 5	1B
Obesity	1, 3	1B
Steroid use	4	2A
Risk with defunctionalized stomas	6	1C
Crohn's disease		
Hand-sewn vs stapled	8	1C
Orientation	8, 9	1C
Immunomodulators	26	2A
Trauma		
Incidence	9	1C
Risk factors	10	2A
Use of NG tubes	11	1B
Presentation of leaks		
Timing of presentation	1, 2	1B
Symptoms	2, 16	1B, 1A
Gastric bypass	12	1B
Diagnostic imaging		
Timing of studies	19, 20	2B, 2A
Contrast enema	2, 15	1B, expert opinion
CT with contrast	2, 15	1B, expert opinion
Nuclear imaging	18	2A
Gastric bypass	12, 16	1B, 1A
Gastroesophageal leaks	17	2A
Therapy		
Surgical intervention	16	1A
Percutaneous drainage	21, 22	2B, expert opinion
Adjuncts to surgical treatment	23, 24	Guidelines
Treatment of fistulas	25	2B

upper GI studies. Of these 1,200, 59 patients developed a leak. The gastrojejunostomy was the site of anastomotic leak in 67.8% with 5.5% of leaks occurring at the jejunojejunostomy. The gastric pouch was involved in an additional 18%. To highlight the complexity of this process, the leak source could not be identified in 6.8% of patients. Twenty-three patients required reoperation while 36 were successfully treated by nonoperative management. While 49.2% of anastomotic leaks were asymptomatic at time of diagnosis, 11 patients required ICU admission and there were 5 mortalities (8%).(12)

Rates of anastomotic leak have been demonstrated to decrease with increasing technical experience. In a retrospective chart review of 300 patients having undergone laparoscopic bypass, Madan noted a leak rate of 5.3% in the first 150 patients, but only 0.7% in second 150.(13) Demaria and colleagues performed a prospective review of outcomes in 281 consecutive patients and demonstrated decreasing anastomotic leaks over time.(14)

The usual clinical presentation of anastomotic leak is that of fever, leukocytosis, and some degree of abdominal pain. More subtle findings such as a prolonged ileus and a generalized failure

to thrive must also be kept in mind.(2) In a prospective review of 3,018 patients undergoing gastric bypass, the three most common presenting signs of anastomotic leak were tachycardia (72%), fever (63%), and abdominal pain (54%).(15)

The most concerning presentation is that of early postoperative peritonitis, which can carry a mortality of up to 50% and mandates emergent re-exploration.(16)

WHAT DIAGNOSTIC IMAGING TESTS MAY BE OF VALUE?

Aside from the most severe presentations of peritonitis and abdominal sepsis, diagnosis is often made from radiologic studies performed based on clinical suspicion. CT with oral and/or rectal contrast is the mainstay of diagnosis. Contrast enemas under fluoroscopy offer a second option for colorectal anastomoses.

For colorectal anastomoses, both modalities appear to have utility for diagnosis. In one series, contrast enema failed to detect 60% of leaks, while contrast enema was successful in two cases where a leak was missed by CT scan.(2) Contrast enemas have been shown to be more reliable than CT for diagnosis of leaks from distal colorectal anastomoses, but neither study was effective in identifying leaks from more proximal anastomoses.(15) CT with oral and/ or rectal contrast remains the procedure of choice. Like any test, results are both linked to those performing and interpreting the study, but today's CT scans are capable of detecting the majority of clinically significant anastomotic leaks and abscesses.

For upper GI surgery, anastomotic leak in the setting of gastric bypass and gastro-esophageal anastomosis can be difficult to diagnose and have potentially devastating consequences. Ballesta demonstrated a low rate of detection for upper GI series for gastric bypass. In 59 gastric bypass patients diagnosed with anastomotic leak, only 15.3% of leaks were detected by upper GI series.(12) In a prospective multicenter study comprising 3,018 patients, Gonzalez and colleagues identified 63 patients with anastomotic leak, with equal leak rates for open or laparoscopic approach. For these patients, upper GI series detected anastomotic leaks in 30%, while CT demonstrated leaks in 50% .(16) With no definitive imaging modality and a nonspecific clinical presentation, the clinician must maintain a high level of suspicion for anastomotic leak in gastric bypass patients.

Gastroesophageal anastomotic leaks are particularly dangerous given the high risk of mediastinitis and the associated morbidity and mortality. In a prospective study of 52 patients undergoing esophagectomy with gastroesophageal anastomosis, Upponi and colleagues compared the efficacy of CT scan versus fluoroscopy for detecting occult anastomotic leaks. Patients were evaluated between postoperative days 6 and 8. All patients underwent both multi-slice scans of the chest and abdomen with a bolus of oral contrast followed by fluoroscopy with water-soluble contrast. CT was found to be better tolerated with greater sensitivity but with less specificity than fluoroscopy. Important signs on CT exam included mediastinal air or fluid as well as extraluminal contrast.(17)

Nuclear imaging using radiolabeled autologous white blood cells have been examined as a method of determining areas of inflammation and potential infection, such as phlegmons and frank abscesses formed in areas of anastomotic leak. The modality has shown particular utility in detecting complications of Crohn's disease using granulocytes labeled with Technetium-99m hexamethyl

propylene amine oxime (99mTc-HMPAO). For Crohn's patients, 99mTc-HMPAO has been shown to be both sensitive and specific in detecting active inflammation as well as fistulas and abscesses. (18) In the case of anastomotic leaks, further research is needed to define the utility and indications for leukocyte scintigraphy.

Timing of diagnostic studies is an issue of particular interest and has been raised with widespread use of CT scans. Given the extensive period of time over which clinically significant anastomotic leaks may develop, determining a minimum period of time required for radiologically apparent signs of anastomotic leak is of great value. In one review of abdominal CT scans performed on 53 critically ill patients, 70% of scans were considered to be of no help or inconsequential to patient management with no CT scan positive for abscess before hospital day 8, consistent with the average time to diagnose an anastomotic leak.(19)

In a controlled prospective study, 73 patients with clinical suspicion for anastomotic leak underwent CT scan along with 23 patients serving as controls. For those patients with clinically significant anastomotic leak, the only feature seen to a statistically significant extant was loculated fluid with air. In those patients without significant anastomotic leak, free air could be seen up to 9 days postoperatively and loculated air up to 26 days.(20)

WHAT ARE THE CURRENT SURGICAL TREATMENT OPTIONS?

In the event of the patient presenting with clear evidence of peritonitis and sepsis, surgical intervention is clearly mandated without need for further imaging. The goal of surgery should be to clear infected debris from the abdominal cavity and prevent further leak by diversion or reconstruction. For the case of small bowel leaks, resection of the bowel about the anastomosis with subsequent reconstruction may be possible. With colorectal anastomoses, anastomotic resection with diversion by either colostomy or ileostomy is preferred and often unavoidable given the degree of contamination and inflammation associated with leak and abscess formation. If an abscess is identified and evacuated, leaving a drain should be considered.

In the setting of gastric bypass surgery, need for surgical intervention is most likely in the setting of hypotension and oliguria, highlighting the difficulty in detecting these leaks until overt signs of sepsis are evident. Surgical intervention commonly involves drainage of collections and repair and revision of anastomosis. Given a nonspecific clinical presentation and a lack of effective imaging techniques, surgical exploration remains an important component of the treatment algorithm.(16)

As previously noted, the majority of patients will have a more ambiguous presentation and present later in the postoperative period. Oftentimes, diagnosis can only be established by CT scan. For patients who do not present with frank peritonitis and sepsis, but are found to have perianastomotic abscess, percutaneous drainage is the preferred option for initial management. While ultrasound or CT-guided drainage can be done, CT allows better evaluation of surrounding anatomic structures. Ultrasound guided drainage is generally reserved for larger superficial collections where there is less risk of the catheter perforating adjacent organs.

Anastomotic leak can be differentiated from abscess by the characteristics of the drained fluid over time. If persistently large volumes are being drained, typically in the range of 50 ml

or greater, an anastomotic leak must be suspected. This can be further evaluated by contrast injection through the catheter or CT scan with use of oral contrast. A water-soluble contrast agent, such as Gastrograffin, is preferred over barium.(21, 22)

The catheter should remain in place until the leak has been healed, otherwise its removal would only lead to a new abscess or potentially sepsis. Serial CT exams at regular intervals of 1–2 weeks will demonstrate how well the collection is draining. CT combined with catheter injection of contrast or a CT "tube-check" gives the physician the ability to evaluate both how well the collection is being drained and if the leak persists. In the more common setting of a subacute presentation several days to weeks after the initial procedure, percutaneous drainage offers an opportunity to drain the abscess and heal the anastomotic leak while sparing patients the added morbidity of surgical intervention.

We have been successful with percutaneous drainage of a subacute leak from a colorectal anastomosis. The patient was a 55-year-old obese male who initially presented with diffuse peritonitis and found to have a freely perforated sigmoid diverticulitis. The patient underwent sigmoid resection with an end-sigmoid colostomy. Following a period of recovery, the patient underwent a colostomy reversal with a handsewn colorectal anastomosis. Intraoperative air-insufflation of the rectum demonstrated no leak and the patient had an otherwise uneventful postoperative course, being discharged on hospital day 6 tolerating diet and having full return of GI function.

The patient subsequently presented on postoperative day 13 with abdominal pain and fever. A CT scan demonstrated a large collection in the pelvis, which was subsequently drained. The patient was admitted, made nil per os and placed on broad-spectrum antibiotics and antifungal coverage. Catheter volumes remained greater than 50 cc for several days, but the patient did defervesce and was able to tolerate a diet within 72 h of percutaneous drainage. The patient was discharged on a 10-day course of oral ciprofloxacin. Weekly office visits and serial CT exams were used to monitor the patient's progress. The pigtail catheter was removed in the outpatient setting 6 weeks after placement without complication (Figure 60.1–60.4).

WHAT CURRENT ADJUNCTS ARE THERE TO SURGICAL CONTROL?

As an adjunct to drainage, we recommend starting the patient on intravenous antibiotics for broad-spectrum gram-negative, and anaerobic coverage. Recommended antibiotics include those active against gram-negative aerobic and facultative bacilli as well as beta-lactam-susceptible gram positive cocci.(23) This is especially warranted where patients present with fever and leukocytosis. Empiric coverage should be extended to obligate anaerobic bacilli for anastomotic leaks of the distal small bowel and colon, as well as for more proximal leaks in the setting of a distal obstruction.

In patients who are immunosuppressed or malnourished, empiric antifungal coverage should also be considered. As patients'
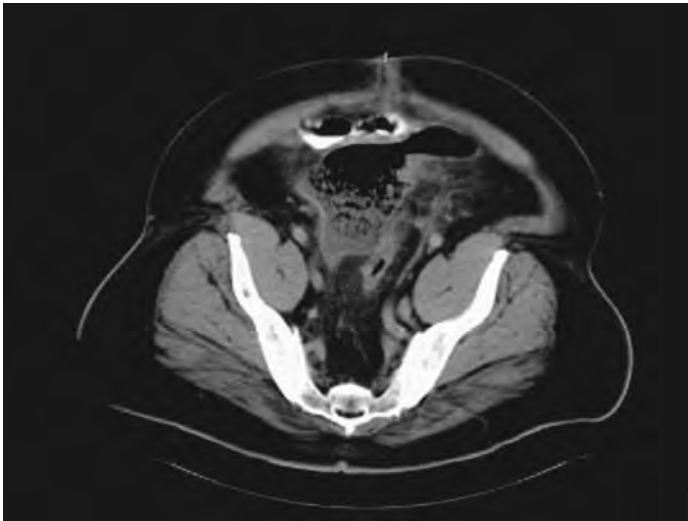
Figure 60.1 A12 cm abscess discovered on presentation to ER.

Figure 60 2 Pigtail catheter within collection, now 7 days after placement.

Figure 60.3 Note significant resolution of abscess by post-procedure day 20.

Figure 60.4 Resolution of collection 40 days after diagnosis.

clinical symptoms improve and they are able to tolerate oral intake, antibiotics can be converted from IV to oral and phased out with further improvement in symptoms. Exact timing of antibiotic therapy remains at the discretion of the clinician based on patient assessement, but a standard period of 7–10 days is appropriate. The Infectious Diseases Society of America (IDSA) strongly recommends that any infectious process of the abdomen not responding to antibiotic therapy with 5–7 days should undergo additional diagnostic investigation.(23)

The IDSA denotes intra-abdominal infections occurring after elective emergent surgery as health-care associated intra-abdominal infections where more resistant flora are often seen, underscoring the importance of empiric broad-spectrum coverage. A lengthy preoperative hospital admission and greater than 48 h of postoperative antimicrobial therapy are held to be significant indicators for infection with resistant organisms at a later point. By extension, judicious use of empiric antibiotics may ultimately help control severity of infection were an anastomotic leak to occur.(23)

Sepsis in the setting of anastomotic leak can be a devastating occurrence. In addition to source control, drainage and empiric antibiotic coverage, adequate and aggressive resuscitation are keys to successful management. The Surviving Sepsis Campaign sponsored by the Society of Critical Care Medicine has established evidence-based guidelines for management of sepsis independent of source. Key recommendations include early goal-directed resuscitation within 6 h of the diagnosis and administration of broad-spectrum antibiotic therapy within 1 h of diagnosis. Preferred vasopressors are norepinephrine and dopamine, with crystalloid and colloid held as being of equal efficacy resuscitation fluids.(24)

Formation of a fistula remains a dreaded complication of anastomotic leak. In these situations, continued drainage is imperative. Bowel rest and appropriate nutrition are important components of patient therapy. The patient may require total parenteral nutrition or an elemental diet largely absorbed in more proximal portions of the intestine. If the patient is able to tolerate oral intake, with no increase in drainage, then oral diet should be continued as this

remains the most effective and least complicated method of maintaining nutrition. Certainly such patients must be carefully selected with frequent re-evaluation by the surgeon.

In the case of small bowel anastomotic breakdown, one method of approach has been exteriorization of the small bowel with creation of a stoma or stomas. This has been combined with continuous enteral nutrition and reinfusion of enteric succus.

Calicis and colleagues have reported on their experience with this technique in 21 critically ill patients requiring laparotomy for postoperative peritonitis. They reported one mortality and seven patients as early failures of treatment. Fourteen patients suffered either medical or surgical complications, including septicemia secondary to central venous access and pneumonia. Three patients required re-operation, including one for bowel obstruction and a second for and ileal fistula.

Of the 13 patients tolerating long-term treatment, the mean duration of continuous enteral nutrition with succus reinfusion was 58 and 61 days, respectively, while the median time to restored intestinal continuity was 82 days.(25)

WHAT SPECIAL CIRCUMSTANCES NEED TO BE KEPT IN MIND WHEN MAKING DECISIONS FOR TREATMENT?

Healing of an anastomotic leak largely depends on the health of the bowel segment. Active Crohn's disease, radiation changes or a distal obstruction can all undermine healing. Distal obstructions must be corrected to allow normal passage of succus and prevent diversion through the anastomotic leak. Leak in the presence of Crohn's disease can result in significant morbidity for the patient, often requiring strict bowel rest and total parenteral nutrition (TPN). Use of immunomodulators such as 6-mercaptopurine and methotrexate may reduce the risk of abscess, leak, or fistula. In a multivariate analysis, Tay and colleagues demonstrated a significant reduction in these events following bowel anastomosis or strictureplasty with the use of immunomodulators.(26)

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61 Anesthesia for bedside surgical procedures
Richard P Dutton

A 40-year-old intoxicated male presents to the trauma center after being struck by a motor vehicle while crossing the street. He is agitated and combative on admission, and undergoes immediate rapid sequence induction and intubation via direct laryngoscopy. Chest radiography reveals multiple right-sided rib fractures with a large flail segment and evidence of hemothorax. A right-sided tube thoracostomy is performed, with return of 500 ml of dark blood over the next hour. Computed tomography (CT) reveals right-sided pulmonary contusion. Fourteen days later, the chest tube has been removed, but the patient cannot be weaned from mechanical ventilation. He is on a bi-level ventilation mode with a high pressure of 28 cmH$_2$0, a low pressure (positive end-expiratory pressure [PEEP]) of 10 cmH$_2$0, an inspiratory–expiratory ratio of 2:1, mean airway pressure of 22, respiratory rate of 16, and FiO$_2$ of 0.35. Arterial blood gas analysis shows a PaO$_2$ of 68, PaCO$_2$ of 48, and pH of 7.38. Interruption of ventilation for nursing procedures or tracheal suctioning is associated with rapid arterial oxygen desaturation. When sedation is lightened, the patient is agitated and requires restraint to prevent self-extubation. Chest radiography reveals bilateral infiltrative disease. The patient requires antibiotic therapy for a gram-negative ventilator-associated pneumonia. Open tracheostomy at the bedside is scheduled, and anesthesia assistance is requested.

BEDSIDE PROCEDURES

A busy trauma and acute care surgery practice will generate numerous bedside invasive procedures, ranging from reduction of fractures and suturing of lacerations in the emergency department (ED) all the way through emergency laparotomy on patients on multiple life-support therapies in the intensive care unit (ICU).(1) Table 61.1 lists invasive procedures commonly performed outside of the operating room. Tracheostomy is one of the most common. This chapter will explore the benefits and risks of bedside procedures, the indications for various anesthetic plans ranging from mild sedation to general anesthesia, and the most common pitfalls encountered.

The greatest advantage of a bedside procedure is logistic. By not transporting the patient to the operating room enormous savings in time, personnel, effort, and expense are achieved, conserving precious resources (especially operating room time) that can be devoted elsewhere.(2) Indeed, for an open tracheostomy in a patient such as this one, time taken to transport to and from the operating room and to move the patient to and from the operating room table, could be twice as long as the procedure itself.(3–6) This is true of many of the short and relatively simple procedures performed at the bedside. However "short" does

Table 61.1 Invasive Procedures Commonly Performed Outside of the Operating Room.

- Central line and peripherally inserted central catheter (PICC) placement
- Placement of fiberoptic and intraventricular catheters for intracranial pressure monitoring
- Tube thoracostomy
- Suturing of lacerations
- Maxillomandibular fixation
- Reduction of displaced fractures and dislocated joints; traction pin placement; splinting
- Percutaneous endoscopic gastrostomy
- Percutaneous and open tracheostomy
- Suprapubic tube placement for bladder drainage
- Complex dressing changes; placement of vacuum-assisted closures
- Reopening of infected surgical wounds; minor debridement
- Emergency release of abdominal compartment syndrome
- Venous and arterial cannulation for extracorporeal support

not mean "painless" and "simple" does not mean "safe." From the patient's perspective, bedside procedures may be overly abrupt, painful, and anxiety-provoking, particularly if the standard of analgesia and sedation falls below the operating room norm.

There is a trade-off in safety associated with bedside procedures. For the provider, there are risks associated with being away from the operating room, risks associated with anesthetic medications, and risks presented by the critically ill patient. For the patient there may also be a gain in safety: each transport of a critically ill patient carries a small—but nonzero—risk of mechanical compromise of diagnostic and therapeutic equipments (e.g., endotracheal tube kinking or inadvertent extubation), iatrogenic complications (e.g., bolus dosing of a pressor), or unrecognized change in patient status occurring during a period of diminished monitoring, or in the hand-off from one care team to another. Avoiding the risk of transport becomes more significant with patients requiring more complex care: advanced ventilator modes, multiple pressors, complex diagnostics, continuous renal replacement therapy, or even extracorporeal cardiac or pulmonary support.

Table 61.2 summarizes the pros and cons of performing procedures at the bedside. Surgery at the bedside is limited by the degree to which the environment can be properly sterilized, the quantity and variety of surgical equipment on hand, and the training and experience of the personnel available to assist. The ICU environment is inherently less sterile than the operating room, and this deficit cannot be readily corrected.(7) Any procedure to place permanent hardware (such as orthopedic fixation) or any procedure in a sterile body cavity (such as exploratory laparotomy) is much better performed in the operating room, with its limited personnel access, increased air flow, emphasis on sterile technique, and more frequent and aggressive cleaning.

While any person or thing available in the operating room can theoretically be moved to the ICU for a procedure there, at some point this becomes more complex than moving the patient to the operating room. These risks are aggravated by complex surgical procedures

Table 61.2 Pros and Cons of Surgical Procedures at the Bedside.

Pros	Cons
Less time required for procedure	Reduced procedural sterility
Transport personnel not needed	Extra equipment not available
No need to move patient from bed to table	Harder to position patient and surgeon
Uninterrupted ICU monitoring	Less availability of operating room nursing
Uninterrupted mechanical ventilation	Less availability of anesthesia expertise
No care team hand-off	

	MINIMAL SEDATION "anxiolysis"	MODERATE SEDATION "conscious sed."	DEEP SEDATION	GENERAL ANESTHESIA
RESPONSE	Normal to verbal commands	Purposeful to verbal/tactile stimulation	Purposeful to repeated or painful stim	None to painful stimulation
AIRWAY	Unaffected	No intervention required	Intervention may be required	Intervention often required
SPONT. VENT.	Unaffected	Adequate	May be inadequate	Frequently inadequate
CV	Unaffected	Usually maintained	Usually maintained	May be impaired

Figure 61.1 The continuum of sedation. Source: Ref(8).

(more likely to require specialty equipment) and sicker patients (more likely to require increasing numbers and expertise of practitioners). Delays in availability of needed equipment or personnel can be more than merely annoying if they endanger the patient either directly (e.g., lack of a vascular clamp when it is wanted) or indirectly (increased risk of infection from increased time with an open wound).

Assuming no risk factors that would make the procedure itself more difficult (e.g., morbid obesity, prior anterior neck surgery), the patient presented would be a reasonable candidate for a bedside procedure. The risk of tracheostomy itself is probably outweighed by the benefits it will offer this patient in terms of ease of ventilation and improved pulmonary toilet. High ventilator settings will make him more likely to decompensate if stressed, but correspondingly increase the risk and difficulty of transport. This patient has a history of desaturation when ventilation is interrupted, due to the need for high and sustained distending pressures to maintain alveolar recruitment. Transport to the operating room could be associated with significant pulmonary instability. One alternative is to move the patient on a portable ventilator so that effective settings can be maintained, but this increases the time, difficulty, and expense of transport.(8) In institutions that are not prepared to do this, the patient would truly be "too sick to travel," and a bedside procedure would be a more attractive alternative.

A common consideration is the need for an anesthesiologist during the bedside procedure. Anesthesia time outside the operating room is in short supply and difficult to schedule, and most specialists in critical care have the necessary skills in pharmacology and airway management to care for a straightforward patient undergoing a straightforward procedure. For example, many bedside tracheostomies are performed safely and efficiently without the involvement of the anesthesia service, using the same medications already being used for sedation and analgesia.(9) The principle which should be applied is that the patient should receive the same quality of care whether in the bedside or the operating room, and whether managed by an anesthesiologist or another physician. This concept has been reinforced lately by The Joint Commission's requirement that bedside procedures meet the same informed consent and "Universal Protocol" standards that operating room procedures do.(10)

While performing bedside procedures without an anesthesia provider can make scheduling easier, and can allow greater productivity in the face of limited resources, there are also some benefits to consider. The presence of an anesthesiologist allows the surgeon to devote his full attention to the technical procedure, and provides an extra pair of experienced hands if difficulties are encountered. The anesthesiologist can contribute a

greater knowledge of useful medications and techniques, including pharmacology for analgesia and sedation; the use of local or regional anesthetic agents; support of the airway and ventilation; and manipulation of fluids, inotropes, and pressors.

> In the case under discussion, anesthesia support should be requested whenever the patient is known to have a difficult airway, is on high ventilator settings, is hemodynamically unstable (on pressor agents or extracorporeal circulatory support), or is requiring active management of elevated intracranial pressure.

HOW ARE THE NECESSARY COMPONENTS OF OPTIMAL ANESTHESIA (AMNESIA, ANALGESIA, FACILITATION, AND HOMEOSTASIS) ACHIEVED AT THE BEDSIDE?

"Anesthesia," the medical product of anesthesiologists, consists of four distinct components. The first is known variously as sedation, amnesia, or unconsciousness, and is the process of rendering the patient insensible to the procedure. Analgesia is the second component: the prevention or ablation of pain. The third component is facilitation of the surgical procedure, including everything, from positioning the patient properly to provision of muscle relaxation for surgical exposure. The final task is the most important: the maintenance of patient homeostasis and safety—throughout the periprocedural period. This includes such things as fluid resuscitation, warming, preservation of the airway, adjustment of mechanical ventilation, and titration of vasoactive medications. Depth of anesthesia falls along a spectrum from mild sedation all the way to coma (Figure 61.1), (11) and is not always predictable for given medication dosages. Individual variation in response means that the anesthesia provider must always be prepared to deal with the next deepest level than the one intended for the procedure; this is why providers of moderate sedation must have training in airway management.(10)

Not every anesthetic requires all four components. Children anesthetized for magnetic resonance imaging (MRI) scanning require sedation and often muscle relaxation, but not much analgesia. Women undergoing Cesarean section need analgesia and muscle relaxation, but do not desire sedation. Part of the art of

anesthesiologist is an appreciation for a given patient and procedure, and construction of an anesthetic plan that will best and most safely accomplish the indicated surgery. Thinking in this fashion helps identify the necessary components of the anesthesia for any given bedside procedure.

Amnesia

Amnesia is usually desirable, because most bedside procedures have the potential for causing pain and anxiety. The patient presented is already exhibiting signs of delirium due to prolonged ICU admission, complicated by ongoing sedative medications, withdrawal from alcohol, circadian disorganization, pain, and malnutrition. Even though the patient is unlikely to consciously remember the events of open tracheostomy (especially if adequate analgesia is supplied), implicit or subconscious memory formation may contribute to post-traumatic stress disorder. Amnesia in the operating room is commonly provided using volatile anesthetic agents (e.g., isoflurane) delivered via the anesthesia machine; in the ICU this option is not available. An intravenous (IV) agent will therefore be required, and numerous choices exist. For a short procedure such as tracheostomy a short-acting agent is desirable, ideally one that will not complicate the patient's ongoing struggle with delirium. A continuous infusion of propofol or dexmedetomidine would be ideal: either agent can provide as much sedation as required, with minimal hemodynamic consequences in an adequately hydrated patient; both agents clear rapidly from the circulation once the infusion is halted.(12)

Both propofol and dexmedetomidine are already in common use as sedative agents in routine ICU practice—given by continuous IV infusion titrated by the bedside nurse to the desired degree of sedation. There exist a number of sedation assessment scales which are used to document the patient's degree of orientation during ICU care, and which serve as the basis for titrating sedative medications.(13, 14) One such scale is presented in Table 61.3. In general, good ICU practice in recent years has focused on minimizing sedation. The more awake the patient is, the less pulmonary deconditioning they experience and the fewer episodes of delirium.(15) This goal must be balanced against the risks of an awake patient undergoing critical care: inadvertent removal of monitors, drains, and airway support devices, increased conscious experience of pain, and the potential for aggravating unstable orthopedic or soft-tissue injuries.

Procedural sedation in the ICU may be as simple as increasing the already running dose of propofol or dexmedetomidine, or supplementing the infusion with an IV bolus. Complications of this approach include not waiting long enough for the change in dose to have an effect (leading to patient anxiety), increasing hemodynamic instability (due to increased vasodilatation and decreased inotropy), inadvertently hypoventilating the patient (due to slowing or interruption of spontaneous ventilator efforts), and mistaking increased sedation for analgesia. Propofol does not have direct analgesic effects; (16) although the sedated patient may not remember experiencing pain, the physical consequences (tachycardia, hypertension, increased release of catechols and other stress hormones) will still be present.

Analgesia

Analgesia is required for most bedside procedures to offset the pain of surgical incision and stimulation of injured tissue. Painful sensations are conducted by sensory nerves from tissue through the spinal cord

Table 61.3 The Richmond Agitation-Sedation Scale (RASS) Source: Ref(10).

Score	Term	Description
+4	Combative	Overtly combative, violent, immediate danger to staff
+3	Very agitated	Pulls or removes tube(s) or catheter(s); aggressive
+2	Agitated	Frequent nonpurposeful movement; fights ventilator
+1	Restless	Anxious but movements not aggressive or vigorous
0	Alert and calm	
−1	Drowsy	Not fully alert, but has sustained awakening (eye opening/eye contact) to *voice* (**>10 s**)
−2	Light sedation	Briefly awakens with eye contact to *voice* (**<10 s**)
−3	Moderate sedation	Movement or eye opening to *voice* (**but no eye contact**)
−4	Deep sedation	No response to voice, but movement or eye opening to *physical* stimulation
−5	Unarousable	No response to *voice or physical* stimulation

Procedure for RASS Assessment
1. Observe patient
a. Patient is alert, restless, or agitated. (***score 0 to +4***)
2. If not alert, state patient's name and *say* to open eyes and look at speaker.
b. Patient awakens with sustained eye opening and eye contact. (***score −1***)
c. Patient awakens with eye opening and eye contact, but not sustained. (***score −2***)
d. Patient has any movement in response to *voice* but no eye contact. (***score −3***)
3. When no response to verbal stimulation, physically stimulate patient by shaking shoulder and/or rubbing sternum.
e. Patient has any movement to *physical stimulation*. (***score −4***)
f. Patient has no response to any stimulation. (***score −5***)

and into the brain. Analgesia is achieved by interruption or modulation of neural transmission at one or more levels of the nervous system. Current theory suggests that using smaller doses of medications at multiple levels provides more effective relief, with fewer side effects, than a large dose of a single agent.(17) Pain experienced by the spinal cord and/or brain also leads to chemical and conformational changes of nervous tissue, including increased production and upregulation of receptors, which will amplify future painful sensations.(18) This phenomenon explains, in part, the tolerance that develops to analgesic medications, and also suggests that the earlier and more effectively the pain is treated, the less of a long-term problem it will become. Use of local and regional anesthesia can block painful stimuli before they reach the spinal cord, thus preempting "wind-up" of pain receptors. Surgeons have been using local anesthetic wound infiltration as both primary and adjuvant analgesic therapy for many years, and this process should be encouraged.

Involvement of an anesthesiologist with skill in regional anesthesia can greatly expand the analgesic options for the emergency surgery or trauma patient, on both a chronic and acute (periprocedural) basis.(19) A thorough discussion of regional anesthesia options is beyond the scope of this chapter, but Table 61.4 lists regional anesthesia options for some of the more common bedside procedures. Most forms of regional anesthesia can be administered either as single doses or continuous infusions through indwelling catheters. The former approach typically uses

Table 61.4 Regional Anesthetic Options for Bedside Procedures.

Procedure	Options:	Comment:
Central line	Local anesthesia	
Tube thoracostomy	Local anesthesia Rib blocks Epidural	Epidural is useful for patients with rib fractures or other ongoing sources of pain
Suturing of lacerations	Local anesthesia	Depending on site
Fracture reduction	Epidural Peripheral nerve block	Catheter-based continuous peripheral nerve blockade (femoral, sciatic, popliteal, brachial plexus) is appropriate for patients with open wounds who will need serial procedures as well as ongoing analgesia.
Tracheostomy	Local anesthesia	
Suprapubic tube placement	Local anesthesia Epidural	
Exploratory laparotomy	Epidural Local infiltration	Useful as an adjuvant Useful as an adjuvant, following abdominal closure
Complex dressing changes	Epidural Peripheral nerve block	As for fracture reduction (above)

a concentration and dose of local anesthetics that will produce complete loss of sensation ("surgical anesthesia") in the affected extremity, while the latter uses reduced doses and infusion rates titrated to produce blockade of smaller (sympathetic and afferent sensory) nerve fibers, while leaving larger myelinated motor and sensory nerves relatively unimpaired. The increased use of catheter-based regional anesthesia facilitated by improving ultrasound technology and training can enable the use of a continuous low-dose infusion for chronic analgesia, with bolus dosing of higher concentration solution as needed for procedures. This combined approach is ideal for the patient with an open extremity wound who requires complex vacuum dressing changes (with or without debridement) every 2–3 days.(20) The use of a catheter-based regional anesthetic, either epidural or peripheral, can make a bedside procedure requiring only minimal systemic sedation out of a case that would otherwise require a general anesthetic and an operating room.

The tracheostomy under consideration does not lend itself to regional anesthesia, but could be facilitated by local anesthetics infiltrated at the site of skin and fascial incision or applied topically to the trachea. Systemic narcotics will be required as well, as the tracheal mucosa is very sensitive to stimulation. Depression of airway reflexes and respiratory rate is of minimal concern in this chronically intubated patient. A short-acting IV narcotic—typically fentanyl at a dose of 2–5 mcg/kg—will blunt hemodynamic responses to incision, dissection, and tracheal stimulation throughout this procedure, and will resolve afterwards rapidly enough to allow a quick return to spontaneous ventilator settings.

Facilitation

Facilitation of the procedure refers to all of those anesthetic steps designed to make the case easier for the surgeon to accomplish.

Facilitation includes appropriate positioning of the patient, which may require more creativity in the ICU than in the operating room. For tracheostomy this means supine or beach chair position, with a roll placed behind the shoulders to extend the patient's neck as much as possible (if radiographically cleared of significant trauma).

Muscle relaxation is helpful to prevent patient movement in response to sudden changes in stimulus or laryngospasm in the event of a lost airway. While chemical paralysis can improve the efficiency of many procedures, including tracheostomy, the anesthesiologist must be wary of changes in ventilator performance immediately following the dose of muscle relaxant; newer ICU ventilator modes may rely on the patient's spontaneous efforts to achieve adequate arterial oxygenation, and may thus require adjustment. Short acting agents are preferable. Vecuronium (0.1 mg/kg) or rocuronium (1 mg/kg) are the most commonly used agents, with onset times of 2–3 minutes and duration of an average dose of about 30 minutes. Succinylcholine (1–1.5 mg/kg) will produce more rapid relaxation, but has a very limited duration of action (10 minutes) and the potential to create significant hyperkalemia in ICU patients with new neurologic deficits or prolonged immobility.(21) This drug is typically reserved for high-risk rapid-sequence intubations, but not commonly used as the primary relaxant for surgical procedures.(22)

The anesthesiologist may also be called upon to facilitate a bedside procedure in other ways. During tracheostomy, for example, suctioning of oral and proximal tracheal secretions is required, along with manipulating the endotracheal tube in concert with the surgeon, deflating the cuff and backing the tube out of the way when the trachea is opened, and then switching the ventilating circuit to the tracheostomy tube once correct position is confirmed by the monitored presence of exhaled carbon dioxide.

Homeostasis

Homeostatic maneuvers that may be required during bedside procedures include keeping the patient warm (not usually a concern during tracheostomy), maintaining an adequate perfusing blood pressure in the face of increased analgesia and sedation (by administration of fluids or pressors), and minute-to-minute adjustment of the ventilator in response to changes in patient condition. While adequate anesthesia should preclude sharp rises in intracranial pressure in patients with severe traumatic brain injury, specific intervention (in the form of head-up position, cerebrospinal fluid (CSF) drainage, deepening anesthesia, osmotic agent administration, or short-term hyperventilation) is occasionally required.

WHAT ARE THE ANESTHETIC REQUIREMENTS FOR SPECIFIC PROCEDURES?

The broad principles outlined earlier are modified in specific ways for specific procedures. Three common bedside surgical procedures, as well as the common situation of endotracheal intubation outside the operating room are reviewed in the following.

Tracheostomy

Chest radiography reveals bilateral infiltrative disease. The patient requires antibiotic therapy for a gram-negative ventilator associated pneumonia. Open tracheostomy at the bedside is scheduled, and anesthesia assistance is requested.

Table 61.5 Total Intravenous Anesthesia (TIVA) for Bedside Open Tracheostomy.

Equipment:	Medications, anesthesia record, emergency intubating equipment
Position:	Supine, roll behind shoulders, "beach chair" the bed if possible
Antisialogogue:	Glycopyrrolate 0.2 mg to reduce oral secretions
Amnesia:	Propofol 25–100 mcg/kg/min as a continuous infusion
Analgesia:	Fentanyl 250–1,000 mcg titrated in as 50–100 mcg boluses Lidocaine 1% 10–20 ml local infiltration by surgeon
Muscle relaxation:	Vecuronium (0.1 mg/kg) or rocuronium (1 mg/kg)
Ventilation:	Titrated as needed to preserve oxygenation
Inspired oxygen:	40% during surgical dissection; 100% during tube exchange
Antibiotics:	Cefazolin 1 g, or as dictated by the patient's history

Remove circumferential tape from endotracheal tube prior to draping. Suction oropharynx thoroughly at start of procedure. Switch to 100% oxygen when the trachea itself is opened. Stand by to deflate endotracheal tube cuff and slowly withdraw tube, under the direct vision/palpation of the surgeon. Pass ventilator circuit to the surgeons when the tracheostomy tube is placed. Confirm adequate ventilator compliance and volumes; confirm exhaled end-tidal CO_2.

Table 61.5 outlines a typical anesthetic approach to a bedside tracheostomy. Fentanyl (250–1,000 mcg) and topical lidocaine (20 ml of a 2% solution) provide analgesia, while a continuous infusion of propofol (25–100 mcg/kg/min) provides sedation. A single bolus dose of vecuronium (10 mg) will provide muscle relaxation for the duration of the anticipated short procedure. In a patient like this one who will remain on positive pressure ventilation there is no need to reverse the muscle relaxant at the end of the procedure; it will resolve spontaneously in 30–60 minutes. A dose of glycopyrrolate (0.2 mg) will reduce oral and tracheal secretions, and might prove helpful if bronchoscopy is part of the procedure.(23)

Wound Debridement and Dressing Changes

Both trauma patients and emergency general surgery patients suffering from necrotizing fasciitis will require frequent and potentially painful dressing changes at the bedside. These procedures can range in complexity from simple removal and replacement of a wet-to-dry dressing all the way to surgical debridement of necrotic tissue followed by placement of a complex vacuum-assisted closure. Factors which suggest doing the procedure in the operating room include increased sterility, containment of irrigation fluids, need for extensive debridement, potential for hemorrhage, and requirement for an operating room table (e.g., lithotomy position). Factors which suggest doing the procedure at the bedside include cardiovascular or pulmonary instability (increasing the risks of transport), the need for frequent operations (daily or twice daily dressing changes), and logistical advantages, such as limited available operating room time. The anesthetic approach to bedside dressing changes depends greatly on the specifics of the wound and the physiology and psychology of the patient. For patients already intubated and mechanically ventilated, the simplest approach is usually a bolus increase in analgesia and sedation, moving the patient into the realm of general anesthesia for the duration of the procedure.

Awake and spontaneously breathing patients for bedside dressing change present a greater challenge. Any procedure restricted to an extremity or to the lower torso can be greatly facilitated by a regional block, possibly including an epidural, and this option should always be considered first. A low-dose solution (e.g., 0.125% bupivacaine ± 2 mcg/ml of fentanyl) can be used to provide analgesia at rest, with bolus administration of local anesthesia (e.g., 10–20 ml of 0.25–0.5% bupivacaine) prior to the procedure. Although offering the best analgesia with the least disruption of homeostasis, regional anesthesia is not suitable for every patient. Extremes of body habitus or personality may make this approach impractical, while the need for systemic anticoagulation or the nature of the wound itself may contraindicate placement of an epidural or regional anesthesia catheter.(24) These patients should be managed with moderate to deep sedation, using sedatives and narcotics, in accordance with the principles outlined earlier. The presence of an anesthesia provider will allow for deeper levels of sedation with more confidence in airway support, especially for the first bedside procedure in a given patient. Once a safe and effective plan has been developed, subsequent procedures can often be managed by ICU or ED personnel without the presence of an anesthesiologist. One example of this approach evolved at the Shock Trauma Center is the use of an infusion of alfentanil for complex dressing changes.(25) After an initial titration by an anesthesiologist, the bolus dose of this short-acting narcotic that will allow deep analgesia without inducing apnea is programmed into a patient-controlled analgesia (PCA) pump that can be activated by the nursing staff every 8–12 h for scheduled dressing changes.

Emergency Decompressive Laparotomy

Although not common, there is an occasional need to perform major cavitary surgery at the ICU bedside of critically ill patients. Exploratory laparotomy or thoracostomy is indicated to control sudden exsanguinating hemorrhage or to relieve critical levels of compartment pressure; bedside surgery is necessary when there is not an operating room immediately available, or when the patient's condition is so unstable that transportation to the operating room is not possible. As with the management of acutely exsanguinating trauma patients, the principles of damage control should be followed: surgery should be limited to that necessary to achieve hemostasis, relieve compartment pressure or tamponade, control contamination from a perforated hollow organ, or excise large portions of necrotic tissue (as when ischemic bowel is producing fulminant septic shock).(26) Further surgery in the operating room to restore bowel integrity, complete surgical debridement, or achieve fascial closure, can follow once the patient's condition improves.

Anesthetic considerations for emergent bedside laparotomy are focused on preservation of homeostasis in a rapidly deteriorating patient. Sedation and analgesia are usually kept at ICU basal levels, unless improving hemodynamics (as with opening the tight abdomen) allow for bolus supplementation. Muscle relaxation is required to optimize surgical exposure and ventilator function.

Participation of the anesthesiologist will facilitate rapid volume resuscitation and transfusion and precise titration of vasoactive and inotropic medications. Needless to say, close communication between the ICU team and "visiting" anesthesia personnel is required to achieve optimal results.

Endotracheal Intubation at the Bedside

A final common bedside procedure is intubation or reintubation of the patient who requires airway protection or mechanical ventilatory support. Protocols vary from institution to institution, with anesthesiologists involved routinely, on a case-by-case basis, or not at all. Goals and principles for the procedure are universal, however: the patient should be kept safe, minimally stressed, and as comfortable as possible. While individual patient requirements may vary, substantial experience with emergency airway management suggests that the overall approach with the highest success rate is rapid sequence induction of a deep level of anesthesia and complete muscle relaxation, followed by orotracheal intubation via direct laryngoscopy.(27) Central to success of this approach is understanding by all participants of the *plan* for airway management. This may arise directly from nationally published guidelines such as the Difficult Airway Algorithm of the American Society of Anesthesiologists, (28) or may be modified locally to reflect the particular environment or patient population.

Rapid sequence induction begins with assisted ventilation with a self-inflating bag and mask, combined with cricoid pressure if a full-stomach or delayed gastric emptying is suspected. Medication combines an anesthetic dose of sodium thiopental (3–5 mg/kg), propofol (1–2 mg/kg), ketamine (1–2 mg/kg), or etomidate (0.3 mg/kg) with an "intubating dose" of a rapid-acting muscle relaxant (1–1.5 mg/kg of succinylcholine, 0.1 mg/kg of vecuronium, 1 mg/kg of rocuronium).(29) Succinylcholine will consistently provide the most rapid intubating conditions, but is associated with potentially serious hyperkalemia in patients with acute neurologic diseases, burns, or prolonged bedrest.(21) The dose of the sedative medication should be reduced—to zero if necessary—in the face of age or hemodynamic instability. The dose of muscle relaxant should not be reduced. Direct laryngoscopy should begin as soon as muscle relaxation occurs, and intubation may be facilitated by use of a "bougie" or intubating stylet.(30) Indirect video laryngoscopy using systems such as the GlideScope are gaining in popularity for out-of-operating-room intubations. Numerous anecdotal reports and case series have documented the value of this approach, (31) but there have been no reported prospective randomized trials to date. In any case, successful endotracheal tube placement must be confirmed by the presence of exhaled CO_2, using either waveform capnography or a disposable colorimetric device.(32)

When anesthesia providers are not involved, undermedication of patients being intubated is a common pitfall. Underdosing of sedative medication risks an increased stress response that may manifest as hypertension, tachycardia, or extreme agitation. Underdosing of muscle relaxants may make the procedure substantially harder, and increases the risk of prolonged procedures and damage to the vocal cords, pharynx, or larynx. In either case, insufficient general anesthesia can leave the patient in the "no man's land" between normal conscious respiratory effort and reflex function and complete suppression of hemodynamic and reflex response. In this state—referred to by anesthesiologists as *Stage 2*—pathologic reflex responses such as laryngospasm, bronchospasm, or bradycardia/asystole can complicate the procedure. It is also possible for the patient to wind up in Stage 2 following initial adequate induction, if medications are not redosed during protracted intubating efforts.

Patient condition, especially a history of prior difficult intubations, may suggest an alternative approach to rapid sequence intubation (RSI). Blind nasal intubation, with minimal sedation, is possible for experienced practitioners in hemodynamically fragile patients who are tachypneic but otherwise cooperative. This technique has a substantial learning curve and is therefore becoming a lost art, even among anesthesiologists. Awake intubation using a fiberoptic bronchoscope is indicated for patients with known difficult airways or unstable cervical spine anatomy. This approach requires careful topical application of local anesthetics and a cooperative patient; in urgent situations or agitated patients RSI is usually a better choice.

Difficult intubation is not entirely predictable, so any airway management plan must include a sequence of steps or options to deal with impending disaster. These include use of airway temporizing devices such as pharyngeal or laryngeal mask airways that can relieve airway obstruction and facilitate ventilation. (33) Although not definitive airways—they are not compatible with long-term mechanical ventilation and do not offer the best protection against aspiration—these devices can preserve oxygenation long enough to pursue a more permanent solution. The ultimate step in most airway management plans is placement of a surgical airway, via either cricothyrotomy (faster) or tracheostomy (more stable).

PITFALLS OF BEDSIDE PROCEDURES

The most common pitfall during bedside procedures is loss of the airway, with subsequent desaturation and hypoxia. This can occur due to overly deep sedation in a patient with an unprotected airway, or as the result of a technical lapse during an airway procedure such as intubation or tracheostomy. The former problem is caused by airway obstruction associated with loss of protective reflexes, and is more likely in patients with risk factors for obstructive sleep apnea. Sedation without intubation should be approached cautiously in patients at the extremes of age and in those with known difficult airway anatomy. Provision of supplementary oxygen can provide an additional margin of safety, but may also serve to mask the effects of hypoventilation. For this reason it is important for the provider to monitor the patient's respiratory rate by direct observation of the moving chest wall or indirectly through monitoring of exhaled end-tidal CO_2.(32)

Hypoxia can also occur as the result of changes in ventilator settings necessitated by anesthesia, especially paralysis. While these risks are mitigated by performing the procedure at the bedside, because chronic ventilator settings can be maintained and loss of alveolar recruitment minimized, paralysis can still lead to hypoxia due to changes in pulmonary dynamics and the loss of any spontaneous component of ventilation. The anesthesiologist must be sensitive to this possibility, and prepared to adjust the ventilator as necessary during the procedure. An increase in PEEP or other deliberate recruitment maneuvers may be necessary to

restore adequate ventilation during the procedure. For patients with a known difficult airway—due to facial swelling, obesity, neck immobility, or underlying anatomic abnormalities—it is important for the surgeon and anesthesiologist to discuss the planned sequence of events prior to beginning an intubation attempt, tracheostomy, or other airway procedures.

A second common pitfall of bedside procedures is hemodynamic instability. This is the result of the patient's underlying disease and the negative inotropy and vasodilatation caused by anesthetic agents. The problem is exacerbated during procedures, such as tracheostomy, that are not uniformly stimulating; provision of adequate anesthesia to cover the most painful portions of the operation may lead to hypotension at other times. Pressor or inotropic infusion may be necessary to support blood pressure during general anesthesia. Severe drops in blood pressure associated with bolus doses of sedatives or analgesics may indicate hypovolemia, which should be corrected by cautious fluid infusion. Transfusion therapy should be applied as it would be in the operating room, and may range from the cautious administration of individual units as guided by laboratory testing to rapid empiric infusion of red blood cells, plasma, and platelets in a 1:1:1 ratio for patients with active life-threatening hemorrhage (usually the reason for the emergent procedure).(34)

SUMMARY

Bedside procedures are common and logistically necessary. Although simple in concept and usually rapid in execution, they are usually performed in patients with limited physiologic reserve. Anesthesia to support bedside procedures must meet the same standards of safety and documentation as anesthesia in the operating room, and has the same goals for patient comfort, surgical facilitation, and preservation of homeostasis.

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62 Acute care surgery in immunocompromised patients
Richard J Rohrer

A 45-year-old man with cystic fibrosis undergoes lung transplantation. The patient is maintained postoperatively on cyclosporine, azathioprine, and methylprednisolone. On the third postoperative day, he develops right upper quadrant pain and tenderness, low-grade fever, and a left shift in the white blood cell count (WBC) differential. A right upper quadrant ultrasound is consistent with an acute acalculous cholecystitis. What measures should be taken and why?

IMMUNOCOMPROMISED PATIENTS

Naturally, immunocompromised patients have existed throughout human evolution. Advanced age, malnutrition, cancer, trauma, and primary infections with secondary immune compromise head the list of causes. Deliberately applied immunosuppression is of much more recent vintage. Cortisone was first shown to be effective in treating rheumatoid arthritis in the late 1940s and may represent the prototypic immunosuppressant even today. The coevolution of cancer chemotherapy, organ transplantation, and the management of autoimmune disease have been intertwined with an extensive industry dedicated to the development of biological and pharmacological immunosuppressive agents.

Current transplant immunosuppression commonly entails one or more of a variety of agents (see Table 62.1). Calcineurin inhibitors (CNIs), antiproliferative agents, and corticosteroids are the most common medications used to maintain immune balance between the host and the graft. In the initial phase, there may also be supplemental "induction" therapy, usually with biological agents such as antilymphocyte agents or interleukin receptor blockers. Occasionally, adjunctive treatments like plasmapheresis are used.

The acute care surgeon must have a general familiarity with these agents. They constitute the primary distinguishing feature between the acutely ill transplant or autoimmune disease patient, and everyone else. Though there are important particulars of day-to-day concern for transplant and rheumatology professionals, there are also overarching principles and patterns that are well within the grasp of general surgeons.

The single most important agent to be considered is prednisone, the most commonly used derivative of cortisone. All corticosteroids work by inhibiting the transcription of messenger RNA in mediators of inflammation. This leaves patients less able to "wall off" inflammatory processes in the chest, abdomen, and soft tissues, and with symptoms that may be disproportionately mild compared to the threat posed by their illness. A high level of suspicion must therefore be maintained when evaluating described symptoms. Fever may be blunted or absent. Signs, however, are more reliable: patients with peritonitis often exhibit tachycardia and will have guarding. The peripheral WBC, however, may

Table 62.1 Common Immunosuppressive Drugs.

Drug	Action	Salient side effects
CHEMOIMMUNOSUPPRESSION		
Calcineurin Inhibitors		
Cyclosporine	Blocks interleukin-2	Neurotoxicity, nephrotoxicity
Tacrolimus	production	Hypertension, diabetes
Antiproliferative agents		
Azathioprine, mycophenolate mofetil	Block DNA synthesis	Leukopenia, Diarrhea
Corticosteroids		
Prednisone	Blocks cytokine	Cushingoid habitus, glucose intolerance
Methylprednisolone	Transcription	Osteoporosis, avascular necrosis
Other		
Sirolimus	Blocks interleukin-2 action	Rash, oral ulcerations, hyperlipidemia
BIOLOGICAL AGENTS		
Thymoglobulin	Antithymocyte antibody preparation	Allergic reactions, occasionally severe
Daclizumab, basiliximab	Antiinterleukin-2 receptor monoclonal antibodies	Allergic reactions, rare

be slow to rise in acute inflammation. This combination of unreliable symptoms, unhelpful laboratories, and trustworthy signs means that repeated physical examination is frequently the best way to judge the magnitude and pace of an inflammatory process in a patient on prednisone.

Corticosteroids are legendary for their other side effects as well—cushingoid facies, truncal obesity, diabetes, osteoporosis, avascular necrosis, cataracts—and for this reason they are minimized or avoided by most practitioners today. Many kidney transplant programs now adhere to "pred-free" immunosuppressive protocols, and most heart and liver transplant programs taper prednisone until it is stopped. Nonetheless, some patients do require long-term "maintenance" prednisone. High-dose corticosteroids are also still commonly used for rejection episodes and are also commonplace in the treatment of arthritis, lupus, and inflammatory bowel disease flares. Skills for judging acute inflammatory processes in these patients will be needed for the foreseeable future.(1, 2)

Calcineurin inhibitors, antiproliferative agents, and other immunosuppressants all may affect the diagnosis and treatment of the immunocompromised patients, but will be described in specific situations below.

WHAT KIND OF PATHOLOGY IS THE ACUTE CARE SURGEON LIKELY TO ENCOUNTER IN IMMUNOCOMPROMISED PATIENTS?

By and large, the medical management of early post-transplant patients will be the province of the transplant team, and general medical management of other immunocompromised patients will not differ much from the management of normal patients.(3) The majority of acute surgical conditions that occur early post-transplant are in fact related directly to the graft itself, and as such, will again be managed by the transplant surgeon. These circumstances will not be considered further here.

Virtually all acute surgical conditions in established transplant recipients will involve intra-abdominal infection, bleeding, or obstruction, and soft-tissue infections.

Intra-abdominal infections

Perforating duodenal ulceration was quite common in the early days of transplantation but is now rare. Antiulcer prophylaxis is universal and effective. When it occurs, the hallmarks are abdominal pain, epigastric guarding, and free air under the diaphragm, and surgery with creation of the classic Graham patch is indicated.(4)

Cholecystitis—either calculous or acalculous—is an occasional problem. In previous eras, cholecystectomy prior to kidney transplant was advised for all candidates shown to have gallstones during their pretransplant evaluation. Later, this recommendation was restricted to transplant candidates with diabetes, and today the recommendation has been abandoned altogether. In the asymptomatic patient, imaging of the gallbladder is not even pursued. Today, cholecystitis in the setting of gallstones carries roughly the same incidence, morbidity, and mortality as it does with the general population.(3, 5)

Acalculous cholecystitis is a different matter, however. The incidence is clearly increased in immunocompromised hosts, particularly if one or more other risk factors are present, such as diabetes, hypotension, sepsis, mechanical ventilation, and recent trauma, including elective surgery. If not diagnosed and treated promptly, rapid progression to gangrene is expected. Characteristic right upper quadrant pain is demonstrable in the awake patient. A left shift in the WBC count is seen in 80% of patients and ultrasound is diagnostic. A Hepatobiliary Imino-Diacetic Acid scan is not necessary, except to rule out the condition in questionable cases. Therapy consists of antibiotics directed at enteric pathogens and prompt cholecystectomy, with drainage of surrounding purulence. For patients with strong relative contraindications to surgery, a computed tomography (CT)-guided percutaneous cholecystostomy may be lifesaving. If the underlying circumstances that led to the resolution of acalculous cholecystitis, subsequent cholecystectomy may not be needed.(6–8)

Pancreatitis is another occasional problem in the dialysis, transplant, or otherwise immunocompromised patient. While gallstones or alcohol abuse may be implicated, a substantial proportion is idiopathic or presumed due to immunosuppressive medications. It can be life threatening. As in immunologically normal hosts, the diagnosis is made by upper abdominal pain and tenderness, elevated amylase and lipase, and abdominal CT. Treatment is primarily supportive, as with normal patients. With the advent of fever and collections, antifungal coverage should be instituted along with antibacterial agents against enteric pathogens in the immunocompromised patient. A CT-guided aspiration or pigtail drainage of collections may be very helpful. Immunocompromised patients who require open pancreatic necrosectomy fare poorly, so it is reserved as a last-ditch effort.(9, 10)

With the aging of the post-transplant population, diverticulitis has become the most common serious intra-abdominal inflammatory condition. In the adult with generalized peritonitis and free air under the diaphragm, the likelihood of perforated diverticulitis (vs. other causes) is high enough that beginning with a lower midline incision is recommended. Symptoms and signs include the usual right lower quadrant pain and tenderness. The immunocompromised patient may not "wall off" the process efficiently, and perforation with free air under the diaphragm is common. Mild, localized cases can be managed with intravenous (IV) or oral (per os [PO]) antibiotics, but any recurrence should prompt plans for elective colectomy with primary anastomosis. This is because severe cases, with localized or free perforation, require urgent or emergent colectomy in the setting of unprepped bowel. Because of a high risk of anastomotic leakage, the standard of care in this circumstance is end colostomy with Hartmann pouch.(11–14)

Diverticulitis is common enough that pretransplant colectomy should be considered in all kidney transplant candidates with a history of recurrent diverticulitis requiring treatment with IV antibiotics. Heart, lung, and liver transplant candidates are generally too ill due to their primary pathology for this to be feasible, however.(15)

Neutropenic enterocolitis is a vexing problem, particularly for cancer patients at their nadir in chemotherapy. The hallmarks are fever and right lower quadrant tenderness in a patient with an absolute neutrophil count of less than 500 per mm^3. Diarrhea, possibly bloody, occurs occasionally. Abdominal CT scan will in all cases show diffuse thickening of the cecum, with variable involvement of proximal small bowel and distal colon. The degree of thickening may correlate with ultimate mortality rate. Early treatment with nasogastric suction, broad-spectrum antibiotics, and granulocyte colony-stimulating factor will suffice for most cases. Careful observation is essential. Surgery has been recommended for patients with refractory illness, deterioration despite maximal medical therapy, free perforation, and hemorrhage. Ileocolectomy with end ileostomy and long Hartmann pouch is most commonly needed, but percutaneous cecostomy may be of value in some patients, and proximal diverting loop ileostomy in others. The mortality rate for neutropenic enterocolitis remains about 40% overall, though selection bias makes the literature difficult to interpret.(16, 17)

Finally, appendicitis is as common in immunocompromised patients as in normal. The blunting of inflammatory signs may lead to a delay in diagnosis, however. This is compounded in kidney transplant recipients by the physical elevation of the appendix using kidney grafts, which are commonly placed in the right lower quadrant. Perforation is common at the time of surgery and may not be well localized.

Gastrointestinal hemorrhage

Low-grade gastrointestinal (GI) bleeding—guaiac positive stools in a stable patient—is not uncommon during the initial hospitalization of extrarenal transplant recipients and is usually self-limited. Aggressive evaluation is generally not indicated.

With persistence, or the need for blood transfusions, evaluation via upper or lower endoscopy may be needed.

Significant upper GI bleeding may occur due to peptic ulceration, gastritis, or, after liver transplantation, from residual varices that are decompressed but still fragile. Gastritis and duodenitis may be due to cytomegalovirus (CMV). Further out from transplantation, hemorrhage due to gastric lymphoma as part of post-transplant lymphoproliferative disease (PTLD) may occur. Treatment via medical measures, upper endoscopy, or interventional radiology is successful in the large majority of cases, and open surgery is reserved as the last resort.(18, 19)

Bleeding from the jejunum or ileum is most commonly because of PTLD in the post-transplant population and is usually mild. A Meckel's diverticulum may bleed more vigorously. Capsule endoscopy may be helpful in the patient with persistent oozing and negative upper and lower endoscopy. Small bowel resection will be needed for diagnosis and/or treatment.

Colonic hemorrhage can be severe in the immunocompromised patient. The usual culprits—right-sided diverticuli, arteriovenous malformations and adenocarcinoma—must be entertained, as for any patient. In addition, for the patient in the first few months after transplantation, CMV colitis must be added to the list, and for the patient further out, PTLD is always a threat. The colonoscopy is the mainstay of diagnosis. If bleeding from CMV colitis persists despite treatment with IV ganciclovir, resection of the worst-affected colon with stoma and Hartmann pouch may be needed. Significant bleeding from PTLD will require similar resection and stoma formation in order to judge cell type and guide oncologic therapy.

Bowel obstruction

Once again, all of the usual culprits must be entertained, even in the immunocompromised host: adhesions from prior surgery, internal and external hernias, and colorectal cancer. At the same time, it must be recalled that the most common presentation of GI PTLD is with obstruction of either small or large bowel. Thus, one must be especially careful in the patient who has had an abdominal organ transplant and presents with a picture of bowel obstruction. It may be due to adhesions, and resolve with time and nasogastric decompression, or it may be due to PTLD, in which case early resection is needed. Careful study of serial abdominal CT scans may give hints as to abnormalities in the bowel mucosa near the point of the transition zone between dilated and non-dilated bowel. Lesion causing small bowel obstruction can be treated with sleeve resection and primary anastomosis. With multiple areas of involvement, only truly o lesions should be resected and the others simply noted. An analogy with Crohn's disease pertains here: this is primarily a medical disease and surgery should be as focused as possible. Colonic resections will usually entail stoma formation and Hartmann pouch.(20–26)

Soft-tissue infection

Immunocompromised patients with cellulitis—whether of the lower leg, around a furuncle on the buttock, or on the abdominal wall—need aggressive oversight and management. IV antibiotics are essential, and all purulence must be drained. Necrotizing fasciitis must be entertained, as it is a true surgical emergency. If it cannot be comfortably excluded by clinical examination, an magnetic resonance imaging is indicated. If present, it requires a wide excision

back to unaffected tissue. Fournier's gangrene of the perineum is a particular problem in immunocompromised diabetic patients, for patients may be slow to seek treatment, and tissue planes on multiple surfaces are quickly involved.(27, 28)

In summary, it may be noted that immunocompromised patients with GI bleeding or bowel obstruction may be approached more or less like the immunocompetent patient, with the simple addition of a few diagnoses to the differential. Immunocompromised patients with suspected intra-abdominal or soft tissue infection, however, need a more aggressive initial analysis, frequent re-evaluation in the early hours of illness, and early surgical intervention.

WHAT PITFALLS MUST ONE AVOID?

As described above, the most common pitfall in the approach to the immunocompromised patient is underestimation of the degree or pace of acute pathology, due to relative paucity of inflammatory symptoms and signs. There are, however, a few other noteworthy confounding variables.

Pneumonia, urinary tract infection, and pancreatitis must all be considered when assessing any patient with an acute abdomen. Unfortunately, all three of these conditions are more common in immunocompromised individuals, and therefore extra attention to both "basic" and "exotic" possibilities is needed when contemplating surgery for them. One would hate to complicate a fundamental medical condition with an unnecessary laparotomy.

CMV gastritis, enteritis, and colitis have already been alluded to. It may occur as a primary infection or as "reactivation" disease in a patient who was previously exposed to the virus. In post-transplant patients, it occurs in the early months after transplantation, often with an organ from a CMV-positive donor placed into a CMV-naive recipient. In the HIV/AIDS patient, it may be the AIDS-defining illness or occur in the aftermath of some other opportunistic infection. The worrisome abdominal findings would rarely have been acute, but rather preceded by a variable period of fever and progressive leukopenia. This infection should be regarded primarily as a medical condition and there is a premium upon early diagnosis. This usually entails sending serum samples for CMV DNA and obtaining biopsy specimens by endoscopy—which, of course, imply close collaboration with infectious disease and GI colleagues. Treatment with ganciclovir, with or without CMV immune globulin, may lead to outright cure of an illness that once seemed certain to require surgery. Still, in life-threatening or refractory circumstances, surgical intervention is essential.(3, 18)

On rare occasions, the acute care surgeon will be called to evaluate a post-liver transplant patient with pneumatosis intestinalis described on abdominal CT scan. Such patients require careful clinical correlation. It is quite possible, in the aftermath of portal vein clamping, for mucosal fragility to permit translocation of bowel gas to a submucosal location, in the absence of any true pathology.

A final pitfall is the failure to properly appreciate the comorbidities that so often plague the immunocompromised patient. Cardiac risk factors must be carefully assessed. The chronic inflammation inherent in autoimmune disease, and the dyslipidemia associated with transplant immunosuppression, result in accelerated vascular disease and risk of myocardial infarction and stroke. In the transplant population, the CNIs that form the backbone of modern immunosuppression cause renal vasoconstriction and chronic damage to both

native and transplanted kidneys. Frequently, this will alter plans for radiologic studies (dye load) and drug dosing (including antibiotics). Coagulopathy comes in many forms and it should be taken very seriously. An elevated INR, thrombocytopenia, and platelet aggregation defects due to aspirin and clopidogrel, or uremia, may complicate acute care surgery in these patients. Nutritional compromise is also frequent, particularly in long-term HIV/AIDS patients, many cancer chemotherapy patients, dialysis patients, and recent heart or liver transplant recipients who were chronically ill at the time of their transplant.(29–32)

In consideration of an immunocompromised patient's acutely altered physiology and chronic comorbidities, it is very common for the wisest initial course to be management with percutaneous intervention followed by open surgery as needed. At the very least, these options should be deliberately considered before being discarded.

SURGERY FOR IMMUNOCOMPROMISED PATIENTS

With only a few exceptions, optimal acute care surgery in the immunocompromised patient is more a matter of attitude than of particulars. Preoperative ventilator management, hydration, attention to electrolytes and blood sugar, invasive monitoring, pressor choice, assessment of renal function, and antibiotic choice proceed as for any other patient. If infection with GI organisms is suspected, or the patient has had a long prior hospital course, coverage for fungus and resistant bacteria should be considered.

If the patient has had a transplant, contact with their transplant team is highly desirable, if only to arrive at a tentative plan for ongoing immunosuppression. In serious cases, it is common to maintain a CNI, discontinue an antiproliferative agent, and reduce corticosteroids. However, these choices depend very much upon the organ involved, time of post-transplant, prior history of rejection, and prior compatibility with immunosuppressive medication. There is no way for the acute care surgeon to know these things ahead of time, so consultation with the transplant team at some point is essential.

Prior operative notes, if any, should be reviewed.

Consideration should be given to stress-dose corticosteroids for patients taking prednisone. In principle, a cosyntropin stimulation test would be appropriate for all patients who may be adrenally suppressed. In practice, however, the test is cumbersome to arrange in the acute preoperative setting, the results may be inconclusive, and the downside of administering a modest dose of stress steroid is small. The simplest method, preferred by this author, involves administering hydrocortisone 100 mg IV shortly before induction of anesthesia and taking a "wait-and-see" approach. If the surgery goes smoothly and confidence in the outcome is high, it may suffice to give no more stress-dose steroid, and simply resume preoperative maintenance doses. Other regimens include administering an intermittent boluses or a continuous infusion of hydrocortisone, and tapering the dose over the first three postoperative days. As with many other areas of the acute care of immunocompromised patients, this is an important subject but one for which proper evidence-based recommendations are lacking.(33)

In the conduct of surgery, a conservative mindset is to be encouraged. It is useful as a discipline to plan to do everything one "level"

more conservative than usual, and then see whether circumstances allow you to reasonably talk yourself out of it. This includes the choice and length of incision, conversion from laparoscopic to open surgery, maintaining hemostasis, suture and ligature technique, oversewing of staple lines, creation of secure stomas, insertion of drains, planning for postoperative nutritional support (nasoduodenal tube vs. feeding jejunostomy), the use of retention sutures, and skin closure (primary vs. delayed primary vs. open).

If an appropriately conservative mindset has guided the conduct of the operation, the postoperative course is usually very much like that of an immunocompetent patient with the same pathology. Weaning and extubating, ambulation, tolerance of tube feeds, return of bowel function, and drain management may all proceed along the time course expected for any general surgical patient.

There are a few exceptions, however. Oral prednisone doses should be converted to IV methylprednisolone until GI function has securely returned. Though not precisely equivalent, a 1:1 dosing conversion from prednisone to methylprednisolone is expedient. If the patient is managed with a CNI, the usual preoperative dose is usually given through a nasogastric tube followed by tube clamping for 1 h. Blood levels must be monitored daily with blood samples drawn prior to administration of the morning dose. Here, again, involvement of the transplant team is essential. Wound healing is impaired for patients on immunosuppression, particularly for those on sirolimus. Removal of skin staples is therefore frequently delayed for 3 weeks after surgery.(34)

Postoperative attention to preoperative comorbidities frequently entail rule-out myocardial infarction protocols, and diuretics to maintain adequate urinary volume. Antibiotic courses are often prolonged, and there should be a low threshold to obtain cultures if fever occurs. Early knowledge of any evolution in culture data is invaluable and input from infectious disease consultants can be especially helpful.

CONCLUSION

The aging of the Western population and widespread availability of increasingly successful treatments of malignancy, HIV/AIDS, autoimmune diseases, and organ failure, have led to a growing cadre of immunocompromised patients in most contemporary hospitals. Acute surgical conditions are less frequent than in an earlier era, but no less conspicuous when they do occur. The acute care surgeon should be alert to the unique aspects of care for these patients and able see them through to an optimal outcome.

The lung transplant patient with acute acalculous cholecystitis is made nil per os, and begun on vancomycin and piperacillin/tazobactam. With CT guidance, a pigtail catheter is inserted through liver tissue and into the gallbladder. The patient improves. Two weeks later, with the patient now quite stable, the catheter is removed and antibiotics are trimmed to normal, post-transplant oral prophylaxis. Elective interval cholecystectomy is contemplated for the 6-month point after transplantation, at which point the patient's surgical recovery should be secure, and the level of immunosuppression much lower.

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63 Hyperbaric oxygen therapy: A primer for the acute care surgeon
Louis DiFazio and George A Perdrizet

PREFACE

Historically, most surgical applications of oxygen therapy have focused on supporting tissue metabolism in the contexts of: (1) resuscitation from shock states, (2) acute cardiopulmonary dysfunction, and (3) wound healing. The role played by oxygen biology in wound healing has been extensively addressed by the seminal works of Dr. Thomas K. Hunt and colleagues.(1) Briefly, wound healing is a complex, biological phenomenon that is critically dependent upon oxygen for success. From a clinical perspective, the wound healing response most commonly fails because of infection. From a biological perspective, wounds become infected because of inadequate oxygen tension within the peri-wound tissue. Dr. Hunt has elegantly summarized these early works on oxygen and wound healing with this simple statement, "Oxygen is an antibiotic."(2)

CASE SENARIOS

Severe Crush Injury

A 55-year-old male is transported to the Trauma Unit following a motor cycle crash in which he sustained blunt chest injuries and a Gustilo Grade IIIb open right tibial-fibular fracture. Initial resuscitation and evaluations are performed and a 50% right pneumothorax is treated with a 38Fr thoracostomy tube. There is no air leak or hemorrhage noted. Head, spine, intra-abdominal, and other skeletal injuries have been ruled out. The right lower extremity has a palpable posterior tibial pulse and intact neurologic exam. Orthopedic evaluation leads to urgent operative repair and external fixation. A large area of compromised tissue (>20 cm^2) is encountered and irrigated copiously before applying a negative pressure dressing. The patient has a past medical history significant for mild asthma and Type 2 Diabetes mellitus. Might this patient's right lower extremity benefit from hyperbaric oxygen therapy? If so, what is the most appropriate timing? Does the patient have any contra-indications to hyperbaric oxygen therapy?

Severe Soft-Tissue Infection

A 33-year-old obese, white female is being transferred from a local hospital due to a severe necrotizing fasciitis that has progressed from her left ankle up to the level of her mid-thigh since starting IV antibiotics and debridement 6 hours ago. Evaluation reveals a systolic blood pressure of 90 mmHg, heart rate of 110/min regular, rectal temperature of 102.4F and a blood sugar of 260 mg/dL. Might this patient benefit from hyperbaric oxygen therapy? If so, what is the most appropriate timing? Does this patient have any contra-indications to hyperbaric oxygen therapy?

Severe Diabetic Foot Infection

A 62-year-old male with a 30 year history of poorly controlled diabetes is found comatose at home by family members. The patient is intubated in the field and transported to the emergency room where a diagnosis of diabetic-keto-acidosis (DKA) is made and a Wagner's Grade IV foot ulceration is identified. Fifty percent of the distal forefoot involved with foul smelling, wet gangrene. Remarkably, there is a palpable posterior tibial pulse. The patient is intubated in the Emergency Room and DKA specific therapy is started. The Emergency Surgical Service performs an urgent open, transmetatarsal amputation and admits the patient. Might this patient benefit from hyperbaric oxygen therapy? If so, what is the most appropriate timing? Does this patient have any contra-indications to hyperbaric oxygen therapy?

MODERN HYPERBARIC OXYGEN THERAPY

Each of the clinical scenarios represents a diagnosis in which hyperbaric oxygen therapy (HBO_2T) is indicated. The goal of HBO_2T is to oxygenate compromised tissues, that is, tissues that have become compromised by acute and/or chronic hypoxia, inflammation, and edema. Compromised tissues can be characterized as tissues that are viable but threatened, due to the high risk for development of secondary infection and further tissue loss. Currently, HBO_2T is an accepted therapy for 13 distinct diagnoses, see Table 63.1.(3) The diagnoses in this list have been selected following extensive reviews of the published literature by the Therapy Committee of the Undersea and Hyperbaric Medicine Society (UHMS). Most insurance carriers, including Centers for Medicare Services, reimburse HBO_2T for these diagnoses. All three clinical scenarios presented above have Grade 1 evidence to support the use of HBO_2T. This point is not generally appreciated by health-care providers who lack formal training in Hyperbaric Medicine. As with all medical therapies, the treating physician must weigh the potential risks and benefits of HBO_2T as it they relates to the individual patient.

Each of the patients described above has a potentially life or limb threatening condition that is likely to benefit from the timely administration of HBO_2T. The incremental risk that a patient and their physician must accept when undergoing HBO_2T is extremely small, well defined and manageable (see Risk Considerations section). There are very few absolute contra-indications to HBO_2T. Table 63.2 lists the currently recognized absolute and relative contra-indications to HBO_2T.

The following brief primer of HBO_2T is divided into three sections; General Considerations, Diagnosis-Specific Considerations, and Risk Considerations. The body of knowledge encompassing the practice of Hyperbaric Medicine has grown rapidly during the past two decades, such that Board Certification is now

Table 63.1 Hyperbaric Oxygen Therapy Recommendation Guidelines.

Diagnosis	Recommendation Grade	Level of Evidence
Crush injury	1A	RCT
Diabetic Foot Ulcer	1A	RCT
Delayed radiation tissue injury	1A	RCT
Severe soft-tissue infections	1B	MA
Carbon monoxide poisoning	1B	RCT
Chronic refractory osteomyelitis	2C	Series
Compromised skin flaps	2C	Case reports and animal studies
Thermal burns	2C	Series and animal studies
Intracranial abscesses	2C	Series and animal studies
Air embolism	1C	Case reports and animal studies
Decompression illness	1C	Series, case reports, animal studies
Severe anemia	2C	Series, case reports, animal studies
Refractory mucormycoses infection	2C	Case reports

Source: Gesell (ref. 3)

Table 63.2 Contra-Indications to Hyperbaric Oxygen Therapy.

ABSOLUTE
Untreated Pneumothorax
Current or Recent Bleomycin Therapy
Any of the Following *Uncontrolled or Untreated* Disease Processes- CHF, COPD, Asthma, Psychiatric Disorders, Seizures, Malignancy

RELATIVE
Fever, Temp. ≥ 101.5 ºF
Acute Upper Respiratory Tract Infection/Sinusitis
Remote Bleomycin Therapy
Adriamycin Related Cardiotoxicity
Bullous Lung Disease
ESRD- if volume overloaded
History of Spontaneous Pneumothorax
Need for $FiO_2 > 50\%$

NOT CONTRAINDICATED
Seizure Disorder
Implantable Medical Devices (Pacemaker/AICD)
Mechanical Ventilation
Confinement Anxiety

F_iO_2- fraction of inspired oxygen, CHF- congestive heart failure, COPD- chronic obstructive lung disease, ESRD- end stage renal disease, AICD- automatic, implantable cardiac defibrillator

available and is supported by the American Board of Medical Specialties, under the subspecialties of Emergency Medicine or Preventative Medicine. The surgical management of these cases is addressed elsewhere within this textbook and will not be repeated here.

The objectives of this chapter are follows

- Inform the acute care surgeon of the current clinical diagnoses for which HBO_2T is indicated.
- Present the current contra-indications and risks related to HBO_2T, including hyperbaric chamber safety.
- Introduce the scientific basis for the use of HBO_2T as it relates to the diagnoses encountered in the practice of Acute Care Surgery.
- Present and grade the evidence for the use of HBO_2T in selected diagnoses.

GENERAL CONSIDERATIONS
What are the cellular effects of HBO_2T which support its use in the setting of acute infection, ischemia, and tissue necrosis? Does *HBO_2T offer any benefits beyond what conventional, 100% oxygen therapy has to offer?*
Many diagnoses treated by the acute care surgeon share the common pathophysiology of acute tissue injury from trauma and ischemia-reperfusion events (primary injury). Examples include, hemorrhagic shock, ischemic colitis, closed head injury, toxic megacolon, and severe necrotizing soft-tissue infection. Each of these conditions is also characterized by the presence of compromised tissues by virtue of their inability to resist acute infection and further tissue necrosis. Clinically, tissues become compromised once tissue oxygen tension falls below an oxygen partial pressure (pO_2) of 20–30 mmHg. This degree of tissue-level hypoxia has been shown to correlate with the failure of wound healing and innate immunity.(4–6) In all cases, this compromised state is characterized by tissue hypoxia, edema, acute inflammation, and microvascular dysfunction or occlusion. These pathophysiological events have been referred to as *secondary injury* in the setting of acute traumatic brain injury.(7, 8)

Secondary injuries occur in all tissues as an obligatory response following initial injury.(9–11) Intervention to disrupt the pathophysiological cascade leading from primary to secondary injury is the goal of many medical therapies, for example, acute traumatic brain injury and acute ischemia-reperfusion events. Oxygen tensions within both healthy and diseased tissues are distributed in a heterogeneous fashion.(12) In healthy tissues there is a constant adjustment or auto regulation of oxygen tensions that maintains a desired baseline, tissue-specific pO_2. With tissue injury (primary and secondary) this autoregulation becomes impaired, resulting in areas within the tissue of sustained hypoxia, now at risk for secondary infection and tissue necrosis.

Oxygen is a pharmacological agent with unique therapeutic properties. It is well suited to treat and/or prevent secondary injury, regardless of the nature of the primary insult. HBO_2T can stabilize compromised tissues and disrupt the vicious cycle of tissue hypoxia → inflammation → edema → microvascular occlusion → tissue hypoxia. Oxygen is a unique therapeutic agent because it is a direct vasoconstrictor that increases oxygen tension within tissues. All supportive therapies used in the acute care of the injured and critically ill patient focus on oxygen delivery to tissues. HBO_2T represents an additional method to achieve this end, beyond standard therapies utilizing blood transfusion, intra-vascular volume expansion, mechanical ventilation, and hemodynamic monitoring. Gas diffusion is critically dependent upon the concentration gradient of the gas within the tissue. HBO_2T is able to achieve reversal of tissue hypoxia well beyond ranges reached by conventional oxygen therapy.(13) This increased "pressure head" of oxygen within compromised tissues translates into reduced tissue loss from necrosis and secondary infection.

Tissue hypoxia
Despite the description of the "oxygen paradox" over 50 years ago, the salvage of all hypoxic tissues remains vitally dependent upon

the timely restoration of oxygen to oxygen-deprived tissues.(14) The duration of hypoxia is the single most important determining factor influencing outcomes following acute ischemia-reperfusion or hypoxic events. Following successful resuscitation and reperfusion of ischemic tissues, the failure to completely reestablish tissue perfusion at the microcirculatory level, ("no-reflow phenomenon"), contributes to much of the tissue loss associated with acute ischemia-reperfusion injuries.(15) Microvascular occlusions resulting from the adherence of activated white blood cells (WBC) to vascular endothelial cells is largely responsible for the no-reflow phenomenon.(16) HBO_2T can improve the oxygen delivery to these tissues and can inhibit further pathological WBC-endothelial interactions.(17, 18) This anti-inflammatory effect of high dose oxygen therapy was an unexpected finding and is the focus of ongoing basic science and clinical investigations. Description of these works is beyond the scope of this chapter.(19–21)

Tissue edema

Edema formation creates an impairment of oxygen diffusion through tissues and contributes, in part, to the establishment of the compromised tissue state.(22, 23) Inter-capillary distances increase from a baseline of 80 microns to greater than 160 microns in tissues with edema. Once this occurs, the tissue oxygen tension maybe unable to support wound healing and innate immune responses, even at the highest level of oxygen administration achievable outside the walls of a hyperbaric chamber (1 atmosphere absolute, 1ATA), where 1 ATA = 100% oxygen administered at 1 atmosphere of pressure = 1.0×760 mmHg = 760 mmHg inspired O_2. Similarly 21% inspired O_2 = 160 mmHg and 50% inspired O_2 = 380 mmHg. Resultant tissue oxygen tension will vary in both baseline and disease states.

There is only one mechanism by which clinicians can increase the diffusion distance of oxygen beyond the capillary bed, and that is to increase the pO_2 within the capillary. The diffusion of any gas through tissue is directly proportional to the concentration gradient of that gas dissolved in solution.(13, 24) Dissolved oxygen is the biologically active fraction of oxygen, unbound by hemoglobin and able to diffuse through the interstitial space. Within compromised tissues, small changes in the partial pressure of dissolved oxygen can have very large effects on tissue oxygenation and host resistance to infection. Administration of 80% oxygen to patients undergoing colonic surgery significantly reduced the rate of postoperative wound infection compared to controls receiving 30% oxygen (5% vs. 11%, $p < .01$, respectively.).(25) The reduction in infection rate was associated with significant increases in the partial pressure of oxygen present within the subcutaneous tissues 59 ± 15 mmHg (FiO_2 = 30% = 228 mmHg)-oxygen group versus 109 ± 43 mmHg (FiO_2 = 80% = 608 mmHg)-oxygen group, $p < 0.001$. The beneficial effect of peri-operative oxygen administration on surgical site infections has recently been confirmed and reviewed.(26, 27) HBO_2T treatment of sternal wound infections resulted in reduction in recurrence rates and length of hospital stay.(28) Furthermore, there is no example in which microbial organisms have mutated to become resistant to high dose oxygen, unlike the situation that exist today regarding antibiotic therapy.

A second major effect of HBO_2T on edematous tissues is edema reduction. This effect has been shown in animal models of tibial-compartment syndrome and in a human burn-wound model and is thought to be due, in part, to the vasoconstrictive effect of oxygen.(29, 30) Vascular tone within all tissue beds is regulated by the balance between the partial pressure of oxygen (O_2, vasoconstrictor) and nitric oxide (NO, vasodilator). [Carbon dioxide tension is also involved in this response but has been purposefully excluded from the present discussion.] The O_2-NO balance represents a complex physiological loop that regulates blood flow into all organs based upon metabolic demand. The vessel diameter and arterial-venous blood pressure gradient regulates tissue perfusion according to Poiseuille's Law,

$$Q = \pi \Delta P r^4 / 8\eta l,$$

Where Q = blood flow, R = vascular resistance, P = blood pressure, π = 3.14, r = vessel radius, η = blood viscosity, and l = vessel length.

If there is adequate oxygen tension to meet tissue demands then blood flow decreases due to oxygen induced vasoconstriction and reduced NO levels. If oxygen is inadequate, vasodilatation occurs by a combination of absence of oxygen and increases in tissue NO. For the details of this complex relationship, see Stamler et al. (31) HBO_2T is able to reduce tissue edema associated with acute trauma and inflammation. Thus when a patient breathes oxygen-enriched air (i.e., $F_iO_2 > 21\%$ oxygen) some degree of vasoconstriction and decrease in cardiac output results.(32, 33) Despite these changes in cardiovascular physiology, net oxygen delivery to all tissue beds is increased.

Tissue inflammation

The microvascular occlusion associated with acute inflammation is the end point of a cytokine driven cascade which activates platelets, white blood cells, and microvascular endothelium.(34) The initiating event leading to microvascular occlusion is cytokine-induced WBC adherence to microvascular endothelium. Cytokine regulation of adhesion molecules has been extensively studied and reported in the literature.(35)

The biological goal of the inflammatory response is to contain the infectious process through abscess formation, even at the expense of limited tissue loss. A vicious cycle (tissue hypoxia → inflammation → edema → microvascular occlusion → tissue hypoxia) can become established within compromised tissues and act as a seedbed for the establishment of invasive infection. This is precisely why severe soft-tissue infections, such as gas gangrene, can overwhelm the host so rapidly.(36) HBO_2T can overcome the physiological barrier to oxygen diffusion due to microvascular occlusion. Simply stated, the greater the oxygen concentration gradient that is established within compromised tissues, the further oxygen will diffuse, and therefore, the greater the potential for salvage of compromised tissues.

HBO_2T has been shown to decrease acute inflammation and reduce pathological adherence of activated WBC's to vascular endothelium in pathologic states such as ischemia-reperfusion and acute carbon monoxide poisoning.(17, 37) Hypoxia induced ICAM-1 expression by human vascular endothelial cells *in vitro* is reduced to baseline levels or below following HBO_2T.(38) Patients with severe perianal Crohn's disease had a reduction in systemic

levels of inflammatory cytokines (IL-1, IL-6, and TNF-α) following treatment with HBO_2.(39) The changes in cytokine profile were associated with improvement of the perianal disease. All of these effects are the result of the pharmacologic effect produced by very high dose oxygen therapy. HBO_2T is able to alter the gene expression of many important proteins having primary functions in host defense and repair pathways.(20, 40–43) Pretreatment of rodents with HBO_2T, prior to hepatic resection was associated with increased hepatic regeneration and expression of HIF-1alpha and VEGF.(44)

In summary, HBO_2T can overcome the two primary physiologic barriers to oxygen diffusion within compromised tissues: edema and microvascular occlusion. This effect is achieved simply by increasing diffusion distance of oxygen within these tissues well beyond that achieved by 100% oxygen therapy alone. Furthermore, HBO_2T can do more than simply overcome these barriers. It can literally remove them by decreasing pathological inflammation, reducing edema, and preventing further WBC-mediated microvascular occlusion.

DIAGNOSIS-SPECIFIC CONSIDERATIONS

Each of the following sections contains a brief introduction to the disease process under discussion along with mention of the seminal study in which HBO_2T improved clinical outcome. Lastly, a brief outline of the standard treatment algorithm relevant to that disease process is listed. Details for each algorithm can be found in the Therapy Committee Report of the UHMS.(3)

SEVERE CRUSH INJURY

Will adding HBO_2T to the management of severe crush injuries provide any additional benefit beyond standard, multidisciplinary surgical care? Can the acute tibial compartment syndrome be treated with HBO_2T?

Management of severe crush injuries (Gusitlo Grade IIIb open extremity fracture), presents a challenge to the surgeon. By definition there is direct damage to the involved tissues. A component of this injury is irreversible at the time of presentation, while subsequent secondary injury may be treatable. There is a varying degree of damage to some or all tissues within the zone of injury, including skin, subcutaneous fat, muscle, bone, nerve, and blood vessel. Most commonly there will be an area of maximal injury which is at highest risk for cellular death and a surrounding area of damaged tissue that is potentially viable but compromised.

Immediately following the onset of crush injury is the development of tissue edema. There are two sources of this edema. A vasogenic component results as a direct mechanical effect of the injury and a cytogenic component which occurs as a pathobiological response of the injured and hypoxic cells as they rapidly lose their ability to maintain cellular ionic gradients and intracellular water.(45) Areas anatomically constrained by unyielding fascia, such as the fore arm and lower leg, are particularly at risk for the development of the compartment syndrome due to this tissue edema. The increasing volume within the tissue compartment results in an elevation of compartment pressure causing a collapse of the microcirculation and severe reduction in tissue perfusion. The net result is local tissue ischemia. It has been shown that when tissue oxygen tension falls below 20–30 mmHg there is increased risk of infection and compromised healing response.(4–6) It is well established that neutrophil function is severely compromised in a hypoxic environment. The localized hypoxia also results in a blunted wound healing response due to decreased collagen secretion and fibroblast function.(46)

Crush injuries are closely associated with a variety of other injuries including open fractures, skeletal muscle compartment syndromes, compromised surgical flaps, thermal burns, and frostbite. These conditions all share tissue ischemia as a common pathophysiology and have collectively been referred to as acute peripheral ischemias (API). Initial management of these injuries follows basic surgical tenants. Compromised vascular inflow must be restored. Venous outflow obstruction, as result of compartment syndrome, must undergo urgent decompressive fasciotomy. HBO_2T has no role to play in the treatment of an established compartment syndrome. Its use should not delay surgical intervention. Hyperbaric therapy has shown promising results as an adjunct to surgical care in maximizing outcome from API.(47, 48) The rational for using HBO_2 is to increase oxygen availability to the ischemic tissue and reduce the tissue edema, maintain microvascular circulation and venous outflow. In the early post injury period, perfusion is likely to be inadequate as a direct result of the injury. Increased oxygen tension through the timely administration of HBO_2T will salvage tissues that may otherwise be nonviable due to inadequate oxygen perfusion. Additionally the improved tissue pO_2 supports the host's responses to healing and infection.

The edema reduction associated with HBO_2T is, in part, the result of hyperoxygenation induced vasoconstriction. Although inflow is reduced, the venous outflow is maintained, resulting in a net reduction of edema. The hyperbaric induced vasoconstriction is a unique and somewhat paradoxical in that it maintains tissue hyperoxygenation in the setting of vasoconstriction.

The initial support for use of hyperbaric oxygen to treat crushed tissue was based upon multiple uncontrolled clinical series and extensive animal work.(49) One series reported an amputation rate of 59% in patients receiving daily hyperbaric treatments, whereas the group which had recurring treatments at four hour intervals had no amputations.(50) In 1996, Bouachour et al. (51) presented a randomized, double blinded, placebo controlled trial of HBO_2T in the management of severe lower extremity fractures with crush injuries. Complete healing occurred in 94% of the HBO_2 treatment group and 59% of the controls ($p < 0.01$). Multiple surgeries were required for 6% of the HBO_2 group and 33% of the controls ($p < 0.05$). In all cases, HBO_2T was instituted within 24 of injury occurrence. It was also shown that the treatment group had significantly improved transcutaneous O_2 measurements. Fracture healing in patients over 40 years age was also improved in the treatment group ($p < 0.05$). This increased rate of fracture healing was associated with higher tissue pO_2 measurements. The use of HBO_2T for the management of crush injuries has recently been reviewed.(52, 53)

Objective criteria have been recommended for the decision to use HBO_2T for crush injuries. These criteria take into account the host's ability to respond to injury along with the extent of injury.

Table 63.3 Severe Crush Injuries: HBO2 Therapy Guidelines.

			Host Status		
Gustilo-Type	Infection Rate (%)	Amputation Rate (%)	Normal	Impaired	Compromised
I	<1	0	No	No	Yes
II	3	0	No	Yes	Yes
III-A	<10	0	No	Yes	Yes
III-B	52	16	Yes	Yes	Yes
III-C	42	42	Yes	Yes	Yes

Source: Strauss (ref. 55).

(54, 55) Decision to treat is based on the Gustilo classification of open fractures, see Table 63.3.

Treatment algorithm:

a. Frequency: 3 times on the initial day, then twice daily thereafter for total of 10 treatments.
b. Conditions: 2.8 ATA, 90 min.
c. Adjunctive measures: hydration, antibiotics, tetanus, negative pressure wound dressing.
d. Comments: Indicated for all Gustilo Class IIIB/C injuries and any Class II/IIIA in compromised host.

SEVERE SOFT-TISSUE INFECTION

Is there any evidence that HBO$_2$T will improve outcomes in the setting of severe soft-tissue infection? Furthermore, if the etiology of my patient's infection is due to an aerobic organism, why would adding more oxygen into tissues be helpful?

The nomenclature describing the various types of soft-tissue infections is obscure. For the purposes of this document, we will distinguish between *Clostridial* (gas gangrene, myonecrosis) and non-*Clostridial* (necrotizing fasciitis) etiologies. The non-*Clostridial* etiologies are further broken down into non-*Streptococcal, mixed bacterial* (Type I) or *Streptococcal* (Type II) infections.(56) Severe infections are those cases that pose an eminent threat to life or limb. The initial evaluation and management of severe soft-tissue infection is addressed elsewhere in this text. The surgeon, when confronted with a severe soft-tissue infection, should obtain representative tissue biopsy for histological study and microbiological culture and Gram's stain.(57) If confronted with a severe *Clostridial* infection (*C. perfringens* or *C. septicum*) based on the Gram's stain (Gram positive rods containing spores) then HBO$_2$T should be considered as a life saving therapy and administered at the earliest time point, even prior to surgical intervention should timing permit.

Tissue hyperoxia (tissue pO$_2$ > 250 mmHg) is associated with the rapid arrest of toxin production and will limit local tissue destruction and systemic toxemia.(58) Toxins produced prior to HBO$_2$T have a very short half-life, (on the order of minutes), thus clinical improvement can be seen during the first treatment session.(59) Results from a single institutional experience support early treatment with HBO$_2$T along with aggressive surgical intervention.(60) This management allowed for the rapid control of bacterial proliferation, toxin production and improved demarcation between viable and nonviable tissues. Non-*Clostridial*, necrotizing fasciitis requires aggressive hemodynamic resuscitation, IV

Table 63.4 HBO2T Improves Survival for Severe Soft-Tissue Infections.

	Group Survival (%)		
Etiology	Number (studies/patients)	Control	HBO$_2$T
Clostridial Myonecrosis, Gas Gangrene	22/1,450	55	81
Necrotizing Fasciitis, mixed bacterial or *Streptococcal* fasciitis	18/278	33	79

Meta- analysis from 1975–98.
Source: Clark (ref. 61).

antibiotics and early surgical debridement prior to the administration of HBO$_2$T. A recent meta-analysis (40 studies, >1,700 patients) reviewed the management and outcomes for severe soft-tissue infections (*Clostridial* and non-*Clsotridial*) and found improvement in survival rates was associated with the administration of HBO$_2$T, see Table 63.4.(61) For severe *Streptococcal* infections, in which toxin production maybe a major factor in determining the pathophysiology and clinical outcome, the clinician may also wish to consider the potential benefit from intravenous immunoglobulin (IVIG) administration, in addition to other standard modalities.(62, 63)

A common misconception exists that, because the *Streptococcal* species are aerobic organisms, that they will not be inhibited by increases in tissue oxygen tension. Regardless of the classification of the organism (obligate aerobe, facultative anaerobe or obligate anaerobe), HBO$_2$T is administered with the objective of supporting the host tissues in an effort to stop the advancement of infection and further tissue loss. In these situations, HBO$_2$T is supporting host defenses (WBC function, edema reduction, maintenance of microcirculation), and controlling inflammation and edema. The therapeutic effect of HBO$_2$T in these infections may not be via a direct antimicrobial mechanism, as is the case for infection due to the obligate anaerobic *Clostridial* species.

1. Treatment algorithm for *Clostridial* myonecrosis (gas gangrene)
   a. Frequency: three times/day until stable then twice daily thereafter for a total of 12 treatments
   b. Conditions: 2.8 ATA, 90 min.
   c. Adjunctive measures: hydration, antibiotics, negative pressure wound dressing
   d. Comments: PCN-G 24 million U/d, as divided dose q4–6hrs and Clindamycin 900mg q 8hr, IV.
2. Treatment algorithm for necrotizing fasciitis
   a. Frequency: twice daily until stable then daily thereafter for a total of 30 treatments.
   b. Conditions: 2.8 ATA, 90 min.
   c. Adjunctive measures: hydration, antibiotics, negative pressure dressing
   d. Comments: **Type I** is mixed microbial pathogens thus antibiotics of choice are for above diaphragm: PCN-G 24 million U/d divided as q4–6hr doses IV plus Clindamycin 900mg q8hrs IV; Below diaphragm: Ampicillin 2gm q, IV, Clindamycin 900mg q8, IV and Cipro 400mg or Levofloxicin

750mg. Alternatives Imipenem/cilastatin 0.5gm q6hr IV or Meropenem 1–2gm q8hrs IV. **Type II**: Beta-hemolytic Group A Streptococcus-Clindamycin 990mg q8 hrs IV or PCN 24 million U qd, divided q4–6hrs, IV.

For isolated Staph only infections Nafacillin or Oxacillin 2gm q4hrs IV or Vancomycin 1gm IV q12hrs.

For Toxic Shock Syndrome add IVIG 1mg/kg day 1, followed by 0.5mg/kg on days two and three.(62, 63)

SEVERE DIABETIC FOOT ULCERATION

How can only 90 minutes per day of HBO$_2$T have any effect on the healing of a chronic diabetic foot wound that has now become infected? What's happening during the other 22 ½ hours of the day outside the chamber environment? How long do the effects of a single HBO$_2$ treatment last?

Diabetes mellitus is on the rise in the USA and worldwide. Currently, it is estimated that there are 25 million diagnosed diabetics in the USA. This number has doubled during the past 10 years and is expected to double again over the next 10 years. (64) The life-time risk of developing a pedal ulcer for the diabetic patient is 15%. Pedal ulceration is responsible for the majority of the morbidity and cost associated with the diabetic diagnosis and is commonly the sentinel event preceding hospitalization and major amputation (i.e., below knee or more proximal).

The standard for diabetic medical care includes metabolic management, life-style modification, and medical therapies. Unfortunately, these interventions have not prevented the risk of developing neuropathy, vascular disease and pedal ulceration.(65, 66) Once pedal ulceration has occurred, aggressive institution of medical and surgical therapies are required to prevent major amputation. Aggressive metabolic management, comprehensive wound care, and revascularization procedures are all part of the complex and intensive medical therapies required to effect foot and limb preservation. Approximately 10–20% of pedal ulcers will fail to heal despite the institution of the standard of care as outlined above. It is in this subset of patients that HBO$_2$T can achieve the clinical endpoints of wound healing and limb preservation.

Numerous clinical trials, including randomized, prospective, controlled trials have demonstrated the efficacy of HBO$_2$T in the treatment of severe diabetic foot ulceration.(67–71) HBO$_2$T reduced the major amputation rate in patients presenting with Wagner's Grade 3 and 4 ulcerations from 55% in controls not receiving HBO$_2$T down to 9% in those treated with HBO$_2$T. The clinical trials testing HBO$_2$T for healing of the diabetic foot wound have recently been reviewed.(72) A Cochrane Review reported on four clinical trials (147 patients) and found that there was significant reduction in major amputation rates (number needed to treat = 4) and time to wound healing associated with HBO$_2$T.(73, 74)

The mechanism behind the healing effect of HBO$_2$T in this setting is felt to be due to both early (hypoxia reversal) and late (new gene expression and neovascularization) physiological changes within the wound bed and surrounding tissues, see Table 63.5. The high dose of oxygen administered during a single 90 minute session of HBO$_2$T acts as a trigger for new gene expression and neovascularization. The biological effects of these changes then continue to evolve during the hours and days following treatment.

Table 63.5 Mechanisms of Action of Hyperbaric Oxygen Therapy.

Mechanism	Effect	Time Course	Citation
Reverses hypoxia	Prevents necrotic cell death; supports WBC functions, reduces infection risk	Short: minutes	1–6, 18, 25, 26, 28
Inhibits inflammation*	Decreases WBC adhesion to vascular endothelial cells, tissue edema, and capillary thrombosis	Moderate: hours-days	18–21, 37–39
Stimulates new gene expression	Upregulates cellular growth factors and receptors, downregulates inflammation	Moderate: hours-days	40–44, 75, 76, 78
Mobilizes stem cells	Tissue repair and regeneration-angiogenesis, vasculogenesis	Long: weeks-months	77, 79–81

WBC = white blood cell.
*Reduces tissue edema and microvascular occlusion.

Neovascularization resulting from 20–40 hyperbaric treatments is due to new gene expression, angiogenesis and mobilization of bone-marrow derived stem cells.(75–81)

Patients who failed to respond to 4 weeks of comprehensive wound care therapies and progress to a Wagner's Grade 3 or 4 pedal ulceration represent a small subset (~10–20%) of the diabetic population receiving wound care. Uncomplicated, full thickness ulcerations (Grade 2) are not an indication for HBO$_2$T. Once deep tissues become involved, such as fascia, bone, joint space or tendon- (Grade 3) or greater than 50% involvement of the fore-foot with gangrene- (Grade 4), HBO$_2$T should be administered. It is paramount that the diabetic patient presenting with a lower extremity wound receive a through vascular evaluation to identify and address any surgically correctable vascular disease prior to the addition of HBO$_2$T to their plan of care.

Treatment algorithm

a. Frequency: Daily for a total of 30–40 treatments.
b. Conditions: 2.4 ATA, 90 min.
c. Adjunctive measures: comprehensive wound care, metabolic and nutritional management, culture directed antibiotic therapy, debridement, off-loading footware, and revascularization.

RISK CONSIDERATIONS

What are the incremental risks to which a patient is exposed during HBO$_2$T? Is it possible to safely treat a critically ill patient receiving mechanical ventilation in a hyperbaric chamber?
The adverse events associated with HBO$_2$T and their management are well described in the hyperbaric medical literature. In short, the potential risks associated with HBO$_2$T are minimal in both their frequency and severity. Some published literature reviews tend to overstate adverse events (AE) associated with HBO$_2$T.(82, 83) Rarely has there been a serious AE associated with HBO$_2$T (see Food and Drug Administration's definition of serious AE, 21 CFR 312.32).(84) Most AE's associated with HBO$_2$T would be graded as mild, with an occasional moderate AE occurring. Review of clinical trials report no serious AE's, including during the treatment of critically ill children.(85–87)

- Otic Barotrauma—This is a preventable problem that may be experienced by individuals who have Eustachian tube dysfunction (<10%). Symptoms include tympanic membrane (TM) bruising, pain, bleeding, and perforation. The risk of TM perforation is small because all subjects are taught maneuvers to equalize pressure across their tympanic membranes. The compression rate is carefully controlled by the certified hyperbaric technician in charge of the treatment session. The usual rate of change in chamber pressure is 120 mmHg per minute. However, based upon an individual patient's ability to equalize the pressure within the ear, this rate can be varied to permit a safe, comfortable treatment session. Auditory acuity is not affected by HBO_2T.

- Transient Myopia—Myopia occurs with repetitive hyperbaric oxygen exposures (~15–20 sessions) and is seen to occur in approximately one third of patients. Typically changes reverse over days to weeks following cessation of therapy and return to the patient's pretreatment baseline.

- Pulmonary Barotrauma—A theoretical risk exists within the lungs if, because of disease, free egress of air is impeded during chamber compression/decompression phases of therapy. This is most likely to occur in a patient who is not spontaneously breathing, such as a patient who is actively seizing, a patient supported by mechanical ventilation or experiencing an acute asthmatic episode. Therefore careful monitoring of the patient requiring mechanical ventilation during HBO_2T is required. Mechanical ventilation is not a contra-indication to HBO_2T. Finally, there is a remote risk that a pulmonary bleb could rupture at some point during compression/decompression and result in simple or tension pneumothorax. Therefore, any patient diagnosed with bullous lung disease would have to have this factor weighed relative to the potential benefit of therapy. The physician must be prepared to diagnose and manage a pneumothorax and related complications. The assessment of overall risk-benefit relationship should be made on an individual, case-by-case basis.

- Pulmonary Oxygen Toxicity—Due to the dose and duration of exposures currently used (100% oxygen at 2.4–3.0 ATA for 90 minutes per session), pulmonary oxygen toxicity does not represent a significant risk to patients being treated for the above diagnoses. The only patients that could be at risk are those who, because of underlying cardiopulmonary disease, require chronic administration of supplemental oxygen therapy ($F_1O_2 \geq 50\%$) to maintain normal arterial blood oxygen saturation.

- Central Nervous System Oxygen Toxicity—The most severe, potential risk to which patients are exposed is central nervous system oxygen toxicity and manifests as a self-limited, grand-mal type seizure. The incidence of oxygen induced seizures reported in the literature ranges from 0.003 to 0.2% of all treatments.(88, 89) In situations of medical emergency, such as that posed by CNS-oxygen toxicity, the chamber can be safely decompressed emergently (requiring 3 minutes vs. 10 minute routine) and the patient can be removed from the chamber environment.

- Cardiopulmonary Arrest—There is no increased risk for cardiopulmonary arrest while receiving HBO_2T.

- Chamber Safety—HBO_2 chambers meet very exacting manufacturing standards coupled to a rigorous system of inspection and safety as regulated by the guidelines from the American Society of Mechanical Engineers' Pressure Vessel for Human Occupancy (ASME-PVHO). Safety standards which determine how HBO_2T is delivered to humans have a long track record of being very effective. There is no example of a U.S. hyperbaric chamber within a medical facility ever experiencing an explosive decompression. Compared to many hospital-based, therapeutic environments to which our patients are routinely exposed, the hyperbaric unit is extremely safe. The National Fire Prevention Association defines the safety guidelines as they relate to hyperbaric chambers within medical facilities, see NFPA-99, Chapter 19 "Hyperbaric Facilities".(90)

SUMMARY

Hyperbaric oxygen therapy has entered its modern era coincident with the recent success associated with the treatment of the diabetic foot ulcer and the Centers for Medicare and Medicaid Services National Coverage Decision of April 1, 2003 (35–10).(91) Similar success has now been confirmed in the setting of delayed radiation tissue injury and will contribute to the growing support for this orphaned therapy.(92) This new era is based upon sound scientific principles that have been carefully laid before us by many dedicated clinicians and scientists, some of whose works have been sited here. From a surgical perspective, the works of Dr. Thomas K. Hunt should be read and reread. "Oxygen is an antibiotic." As new knowledge is generated for both the clinical application and basic science understanding of HBO_2T, we speculate that many difficult disease processes will become future targets for testing the HBO_2 hypothesis.(93–96) The potential application to the setting of acute care surgery and extension into the surgical intensive care unit is obvious.(97–99) HBO_2T may permit preconditioning protocols to finally become established clinically.(100–102)

The excellent safety record for the delivery of HBO_2T in U.S. medical centers makes this modality an attractive option from the perspective of clinical decision making. As hyperbaric therapies gain wider recognition of both basic science foundations and clinical successes, the future focus should turn towards improving patient access, expanding mechanisms for clinical reimbursement and funding of clinical trials. Education of our medical and surgical colleagues, as well as residents and medical students is gravely needed.

From the perspective of the acute care surgeon, integration of HBO_2T into the practice of emergent surgery will attenuate the pathologic cascade of events defined by "secondary injury" phenomena and result in reduced tissue loss and improvement in clinical outcomes. Interested readers should consult these references for further information.(3, 103–106)

This list is intended to assist the acute care surgeon in making appropriate patient referrals for hyperbaric consultation. As with all medical therapies, this list does not replace the need for a through and balanced discussion of potential risks and benefits as they relate to the individual patient and their medical condition by an informed physician.

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64 Trauma and surgical critical care system issues
Alan Cook and Heidi L Frankel

You are a general surgeon who has recently completed a trauma/ surgical critical care fellowship. You have joined a practice at a newly designated community Level I trauma center with a free-standing surgical residency and midlevel providers.

- What resources does your Level I trauma center require beyond those of a Level II trauma center? Do these improve outcome and, if so, in what patient population(s)?
- Your Trauma Director and hospital administrator require you to participate in in-house call. Will this affect patient outcome? Will this affect your job satisfaction? How should you be paid for this responsibility?
- Will the use of midlevel providers affect trauma patient outcome?
- What outcome assessment tools are available to judge the quality of care that you and your colleagues deliver to injured patients?

TRAUMA CENTER DESIGNATION

The Committee on Trauma (COT) of the American College of Surgeons (ACS) outlined the criteria for trauma center verification in, "Resources for Optimal Care of the Injured Patient: 2006."(1) In this document, the COT identified various resources and process criteria necessary to distinguish a hospital as a verified Trauma Center. Hospitals are stratified into three levels with Level I being the highest level of Trauma Center. The specific requirements of Level I centers includes admitting 1,200 trauma patients per year or 240 patients with an injury severity score (ISS) greater than 15. A level I center must also have a surgically directed critical care service, train general surgery residents, be a leader in education and outreach activities, conduct trauma research, and participate in injury prevention and control. The depth of personnel and resources required for the tertiary care of the injured and education of physicians, nurses and prehospital providers is typically found in university-based teaching institutions. However, other hospitals may meet criteria for Level I designation. Trauma center designation by the ACS has demonstrated improved outcomes of injured patients. Four studies have shown improvements in patient outcomes, including mortality when hospitals have become designated ACS trauma centers. (2–5) Of note, it has been shown that the risk of death for injured patients is decreased by 25% when cared for at trauma centers versus nontrauma centers.(5) Interestingly, Scarborough and colleagues demonstrated that changing the level of designation of a trauma center from Level II to Level I was associated with a significant reduction in mortality in their trauma population.(6) Demetriades et al. observed improved survival among severely injured patients treated at Level I-designated centers compared with those treated at Level II centers.(7)

In-house call

The issue of in-house call has been the focus of controversy for many years. The requirements of the COT state that, "… It is expected that the surgeon will be in the emergency department on patient arrival, with adequate notification from the field. The maximum response time is 15 minutes for Level I and II trauma centers."(1) Two independent surveys have been conducted to describe trauma practice patterns in the United States.(8, 9) Of the surgeons responding, roughly half take in-house call. An interesting paradox emerged when the membership of the American Association for the Surgery of Trauma (AAST), the Eastern Association for the Surgery of Trauma and the Western Trauma Association were surveyed. Over half of the respondents (54%) favored in-house call as a part of practice for trauma surgeons. Yet, 56% viewed in-house call as a disincentive or impediment to trauma surgery as a career.(8) The outcome benefit of in-house trauma surgeons has also been investigated and no consistent benefit has been demonstrated. Rogers and coworkers compared outcomes between two university trauma centers and found that the involvement of board-certified surgeons in the early resuscitation of severely injured patients resulted in improved outcomes.(10) Durham et al. compared outcomes of patients who met trauma activation criteria before and after implementation of mandatory in-house trauma surgeon call. Significantly, an 8-fold decrease in deaths judged to be preventable was observed after the implementation of the in-house call practice.(11) Contrasting findings were observed by Demarest and colleagues who prospectively compared patient outcomes at comparable Level I trauma centers based on the presence of in-house trauma surgeons versus those who take call from home. Over the 6-month study period, there were no appreciable differences in clinical outcomes between the two groups. There were no significant advantages to in-house call when the average response time was less than 15 minutes. There were trends favoring survival in patients who rapidly deteriorated in the emergency department, patients transferred from other hospitals who met trauma code criteria upon arrival to the trauma center, and patients arriving between 5 PM and 7 AM if the trauma surgeon was in-house.(12) Similarly, Luchette also found few outcome differences between patients resuscitated by trauma surgeons who preferred in-house call versus those taking home call.(13) Among survey respondents, the percentage of trauma surgeons receiving compensation for their call time varied from 19.4% to 34%.(8, 14) When the trauma centers throughout the state of Florida were queried, 90percent of respondents reported paying for on-call trauma coverage. The median annual compensation paid by these hospitals was US$657,000 for trauma coverage by general surgeons.(15)

Midlevel providers in trauma

Nurse practitioners and physician assistants, collectively referred to as "physician extenders" or "midlevel providers", have become

a recent addition on the teams of providers caring for trauma patients. The motivation to add midlevel providers was largely born out of the 2003 mandate from the Accreditation Council for Graduate Medical Education (ACGME) requiring that house staff work hours be limited to 80 h per week with one 24 h period off per week. This impacted trauma teams by effectively decreasing the number of residents available in-house on any given day. Midlevel providers have been added to trauma teams to fill in gaps in the workforce and to provide continuity of care. Reports in the literature as early as the late 1990's demonstrated that physician extenders had a positive impact on the quality of patient care in trauma centers. Investigators at Level I and Level II trauma centers have demonstrated significant decreases in length of stay after the addition of midlevel providers.(16–19) Nyberg and colleagues surveyed trauma patients, physicians and hospital employees at Wesley Medical Center in Wichita, Kansas, a Level I trauma center and found the vast majority of those queried were satisfied with the care provided by the midlevel providers.(20) In addition to inpatient floor duties, midlevel providers have been shown to be effective operative assistants and able to safely perform invasive procedures.(21) In many instances, the efforts and activities of physician extenders can be compensated if the institution can sort through the various rules and requirements of the payers.(22)

Quality measures

Mortality has traditionally been the singular metric by which the quality of trauma care has been measured. Trunkey's seminal description of trauma's trimodal mortality distribution became dogma in the modern paradigm.(23) Centers began being evaluated based on observed to expected mortality, using morality prediction models based on severity of anatomic injury, physiologic derangement, and age. The Trauma ISS (TRISS) (24) and A Severity Characterization of Trauma (ASCOT) (25) are scoring methodologies derived from large trauma databases and have been championed by many for mortality prediction. More recently, investigators have looked beyond mere survival as a measure of quality of care for trauma centers. This is particularly useful as inpatient complications among survivors, physical and psychosocial function, and patient and family satisfaction all provide useful measures of quality medical care and opportunities for improvement. For example, Inpatient complications were tracked and comorbidity and outcome data were gathered on the patients admitted to the trauma service of a level I trauma center using the methodology of the National Surgical Quality Improvement Program (NSQIP). The investigators compared those data to that of the National Trauma Data Bank (NTDB) and the NSQIP data of the general surgical patients of the same institution. The authors concluded that the NTBD underreported complications and the NSQIP methodology provided improved means of effectively tracking and reducing adverse outcomes in a risk-adjusted manner.(26) Functional and psychosocial outcomes can be measured using instruments such as the Short Form 36 (SF-36) health survey.(27) This is a generic indicator of health status and one of the most commonly used instruments of this kind. It measures 36 questions to assess eight areas of patient function and satisfaction. The Functional Independence Measure

(FIM; 28) is a broad measure of physical and cognitive function. This instrument consists of 18 items grouped into six categories including self-care, sphincter control, mobility, locomotion, communication and social cognition. The Glasgow Outcome Scale (29, 30) was developed to provide an objective estimate of outcome following head injury. Through interview of the patient or a proxy on the patient's behalf, functional status is measured. The Functional Capacity Index (FCI; 31) was developed to predict the expected degree of functional limitation for each Abbreviated Injury Scale injury at 12 months postinjury. Although most of these were not specifically designed for the trauma population, they have been used to evaluate patient outcomes following trauma.(32–35)

Your group opts to establish a Surgical Critical Care service with an intensivist model.

- What is the intensivist model and what are the "Leapfrog" criteria? Is 24 h per day, seven days per week (24/7) in-house coverage ideal? What is the ideal staff/patient ratio?
- What is a closed ICU and does this model improve outcome?
- Will the use of midlevel providers affect ICU patient outcome? What other providers should comprise the ICU team?
- Should care be protocol-driven? If so, what aspects?
- How might one measure the quality of care delivered in your ICU?

THE INTENSIVIST MODEL AND
THE LEAPFROG CRITERIA

The specific qualifications, capabilities, responsibilities and activities of an intensivist were defined by the Society of Critical Care Medicine (SCCM) Guidelines Committee in a consensus paper published in 1992.(36) Here, an intensivist is someone trained in an accredited critical care program, promotes quality care in the ICU and uses resources efficiently, practices critical care medicine primarily, and participates in interdisciplinary quality improvement activities. Interestingly, that document calls for 24/7 ICU coverage by critical care intensivists. At least three publications prior to the SCCM consensus guideline paper documented improved patient outcomes and resource utilization with the implementation of a dedicated intensivist staffing model. (37–39)

At approximately this same time, The Business Roundtable, an organization of the chief executive officers for some of the nation's largest health care purchasers, founded The Leapfrog Group. This is an initiative aimed at improving the safety, quality and affordability of health care delivered to the employees of the member organizations. This organization has recommended four improvements, or so-called, "Leaps in hospital quality, safety and affordability." The four "Leaps" include (1) computerized physician order entry, (2) evidence-based hospital referral, (3) Safe Practices score improvement, and (4) Intensivist staffing in ICUs. Additionally, there are four aspects to the intensivist staffing standard: (A) a physician board-certified or board-eligible in critical care should manage or comanage all critical care patients; (B) the intensivist should be present in the ICU during the daylight hours seven days per week without other clinical responsibilities; (C) the intensivist should be able to return ICU pages

within 5 minutes; and (D) another physician or midlevel provider must be available to reach ICU patients within 5 minutes.(40)

Subsequent to the SCCM paper and the dissemination of the Leapfrog mandate, a growing body of literature scrutinizing the costs and benefits of the intensivist staffing requirements has been published. Pronovost et al. retrospectively evaluated the discharge data for patients undergoing abdominal aortic surgery in the nonfederal acute care hospitals in Maryland for a 2-year period. They noted a threefold decrease in ICU mortality when a critical care-certified intensivist conducted daily rounds. Additionally, it was noted that there was a significant decrease in complications when the ICU was staffed by an intensivists.(41) Ghorra and coworkers conducted a retrospective review a tertiary care hospital in Rhode Island that converted its ICU from an open unit to a closed ICU staffed by board-certified intensivists. In addition to substantial reductions in mortality, (14.4% vs. 6.04%, $p = .012$), the overall complication rate and the use of outside consultants decreased. (42) Dimick and colleagues analyzed data from the Maryland Health Services Cost Review Commission to evaluate the effect of daily rounding by an intensivist on clinical and economic outcomes after esophageal resection. It was observed that the lack of daily rounds by an intensivist resulted in an increased length of stay (LOS) of seven days, a 61% increase in total hospital cost, and an increase in complications.(43) A systematic review of available literature was conducted by Pronovost et al. in 2002 to evaluate the association between ICU staffing and patient outcomes. This meta-analysis included 26 observational studies comparing patient outcomes with various staffing strategies. They grouped ICU staffing strategies into two groups for comparison. ICUs were considered "high intensity staffing" if their strategy included mandatory intensivist consultation or was a closed ICU. Conversely, an ICU was considered "low intensity staffing" if they practiced elective intensivist consultation or had no intensivists. They found that high intensity staffing was associated with significantly reduced ICU and hospital mortality and lower ICU and hospital LOS.(44) While mortality and LOS are important outcome measures, intensivist staffing has been shown to improve performance of other process measures. Kahn and colleagues conducted a retrospective cohort study of 29 academic hospitals participating in the University Health System Consortium Mechanically Ventilated Patient Bundle Benchmarking Project. They found that when care of the critically ill was the primary responsibility of an intensivist or when intensivist consultation was mandatory, patients' treatments were more likely to include spontaneous breathing trials, interruption of sedation, and intensive insulin treatment by day four of mechanical ventilation.(45)

In contrast to the above cited evidence favoring an intensivist ICU model, Levy et al. published an analysis of data from Project IMPACT, a voluntary, national database of ICU patients developed by the Society of Critical Care Medicine. Their cohort included over 100,000 patients from 123 ICUs in 100 hospitals in the United States. After adjustment for severity of illness and the propensity for receiving critical care management, the odds of in-hospital death were greater for those patients managed by an intensivist. While they acknowledge the possibility of residual confounders and selection biases for intensivist involvement,

their analysis and conclusions highlight the need for additional outcome research to define the optimum staffing model for the sickest patients.(46)

Finally, it is noteworthy that the Leapfrog intensivist staffing mandate only calls for the intensivist to be on the premises during daytime hours. Many institutions, however, have adopted round-the-clock, on-site intensivist ICU coverage and have published improved outcomes associated with doing so. Gajic and colleagues reported a 2-year prospective cohort study comparing the quality of care and patient/family and provider satisfaction before and after conversion to a continuous 24-h intensivist staffing model. In addition to decreased LOS, they observed improved adherence to evidence-based care processes and decreased rates of ICU complications. A majority of their providers deemed this model as optimal for patient care.(47) This model may not be sustainable as a recent report from the Health Resources and Services Administration (HRSA) of the U.S. Department of Health and Human Services states that the supply of intensivists is growing but will be insufficient to provide the optimal level of care for the United States population through 2020.(48) A novel approach to intensivist staffing was tested in two adult ICUs of Sentara Healthcare, a tertiary care center in Norfolk, VA. The intervention consisted of a telemedicine-based remote intensivist who provided supplemental monitoring and management of ICU patients with physician extenders on-site. As with other studies of intensivist staffing, the authors found lower hospital mortality for ICU patients and shorter ICU LOS. Additionally, the hospital realized financial benefits in excess of the program costs.(49) Little data exist regarding the ideal physician-to-patient staffing ratio. In a retrospective cohort study in a medical ICU at The Mayo Clinic in Rochester, Minnesota, Dara et al. observed a significant decrease in LOS when intensivist-to-bed ratio was less than 1:15.(50) This lone study illuminates an important area of further investigation.

Open versus Closed ICUs
Intensive care units can be classified as either "open" or "closed" units. In the open ICU model, the primary care physician or admitting surgeon direct care for the patient while they are in the ICU and intensivist consultation is elective. The term *closed* ICU refers to a scenario where the intensivist directs patient care while the patient is in the ICU. In addition to the evidence cited above showing improved outcomes when intensivists staff the ICU, there is evidence that the closed ICU performs superiorly in terms of patient survival and LOS. Multz and colleagues, conducted a retrospective analysis of data gathered before and after ICU closure at one hospital and compared that ICU to an open ICU nearby. They found that an open ICU model was associated with more days on mechanical ventilation, greater LOS and higher mortality.(51) Carson et al. also conducted a before and after comparison of open and closed ICU formats. Although the LOS was not significantly different between the two periods, there was a significant difference in the observed-to-predicted mortality ratios demonstrating improved mean survival for patients treated in the closed ICU format. Additionally, it was noted that nurses were more likely to say they were very confident in the clinical judgment of the physician primarily responsible for patient care in the closed

ICU compared to the open ICU format. There were no significant differences in resource utilization reported in this study, however. (52) Two studies have compared ICU staffing formats across multiple institutions to evaluate the effect of the organizational model had on patient outcomes beyond those observed in single institution studies. Treggiari and colleagues conducted an analysis of data from the King County Lung Injury Project. These data, pooled from 24 ICUs in 16 hospitals in northwest Washington, included 1,075 patients with acute lung injury (ALI). In addition to improved mortality, they found that patients cared for in closed ICUs were more likely to receive lung protective ventilation (<6.5 ml/kg predicted body weight). Yet consultation by a pulmonologist in an open ICU was not associated with improved mortality.(53)Nathens et al. used data from the National Study of the Costs and Outcomes of Trauma to assess the effect of ICU staffing models on the outcome of trauma patients. They noted an improved mortality for trauma patients cared for in closed ICU. That effect was most pronounced among elderly patients and when trauma patients were cared for in ICUs staffed by surgical intensivists and in designated trauma centers. They concluded that, "…injured patients are best cared for using an intensivist-model of dedicated critical care…" They further advocated that surgical intensivist staffed ICUs should be considered for inclusion among the criteria for trauma center verification.(54)

Midlevel Providers and the ICU Team

As previously stated in this chapter, midlevel providers contribute to medical teams in a variety of settings, including the ICU. Two factors have influenced the growing utilization of midlevel providers in critical care. First, the supply of intensivists is insufficient to meet the need for staffing the country's' intensive care units. Midlevel providers can act as the effectors or actuators of care under the direction of an intensivist. Second, the supply of physicians-in-training has been effectively reduced by the ACGME 80-h workweek. A survey of the Association of Program Directors of Surgery was conducted to assess strategies of coping with the restrictions of the ACGME 80-h workweek. It was noted that 30 percent of the responders indicated the utilization of physician extenders to help cover the ICU during daytime hours and 11 percent used them at night.(55) Only a few single-institution studies have evaluated the outcomes of care when midlevel providers actively participate in patient management on critical care teams. As early as 1991, Dubaybo et al. evaluated the feasibility of utilizing physician assistants as providers of care in a medical ICU. The performance of the physician assistants as well as the operation of the ICU was measured over a 2-year period. They found that there was no significant difference in ICU occupancy, complication or mortality rates for the period of the study.(56) In a series of four papers published in as many years, Hoffman and colleagues evaluated the work activities, perceptions by team members, and outcomes of nurse practitioners practicing on ICU teams affiliated with the University of Pittsburgh School of Medicine. They found that the nurse practitioner spent more time in activities related to coordination of care and meeting with patients and families as compared to physicians-in-training. They also found that the role of the nurse practitioner was valued by other members of the team and that patient outcomes were equivalent when nurse

practitioners performed in roles equivalent to physicians in training.(57–60)

In addition to the midlevel providers, physicians and nurses, the contemporary ICU team consists of several other contributing members. Pharmacists, dietitians and respiratory therapists have been proven to positively impact the outcome of critically ill patients and have earned a place on the critical care team. The presence of a pharmacist on the critical care team has been shown to be beneficial to the patients by decreasing adverse drug events and to the hospital by decreasing costs. Leape et al. conducted a prospective before and after comparison to measure the effect of pharmacist participation on ICU rounds. They found a 66% decrease in adverse medication events when pharmacists participated on ICU team rounds.(61) Montazeri and colleagues showed decreased hospital cost in a prospective, three month study of pharmacist-initiated consultations in a tertiary care medical-surgical ICU.(62) Kopp and coworkers demonstrated both cost savings and decreased adverse medication events by retrospectively reviewing critical care pharmacist interventions.(63) The value of the critical care dietitian has also been demonstrated in the literature. Braga et al. demonstrated shorter length of stay and improved serum albumin and weight gains among patients when dietitian's nutritional recommendations were followed.(64) The contributions of the respiratory therapists to the ICU team have been documented in numerous publications addressing various mechanical ventilator weaning protocols. For example, Kollef et al. observed that a protocol-guided weaning of mechanical ventilation, as performed by nurses and respiratory therapists resulted in significantly shorter duration of mechanical ventilation. This also realized a cost savings of $42,960 compared with physician-directed ventilator weaning.(65) Two years later that same group, headed by Brook, demonstrated significant reductions in days of mechanical ventilation, lengths of stay in the ICU and hospital, and rates of tracheostomy by following a nursing-guided sedation protocol compared to patients receiving nonprotocol-directed sedation in a randomized, controlled trial.(66)

In addition to the important contributions of a multidisciplinary clinical team to the current practice of critical care, standardized protocols of many processes of care have had an invaluable impact on the outcomes of critically ill patients. The efficacy of daily sedation interruption and spontaneous breathing trials was further demonstrated by Girard et al. in the "Awakening and Breathing Controlled trial". Mechanically ventilated patients in four tertiary care hospitals were randomized to the treatment protocol or they received the usual sedation protocol and a daily spontaneous breathing trial. The protocol-treated patients spent, on average, three fewer days on the ventilator, three fewer days in the ICU and four fewer days in the hospital. Moreover, patients treated per the protocol had a 32% lower risk of death than those in the control group.(67) Tight glucose control demonstrated multiple improved outcomes in patients who were in the intensive care unit for > 5 days in a randomized, controlled trial in Belgium. (68) A nurse-driven insulin infusion protocol was tested in a surgical ICU in a before-after fashion to test its efficacy and safety. They observed more rapid and more effective glucose control compared with physician management.(69) An evidence-based nutritional management protocol was evaluated in a prospective

before and after study by Barr and colleagues. They demonstrated a significant decrease in the duration of mechanical ventilation on the postimplementation group after adjusting for demographics, illness severity, and type of nutritional support.(70) Such protocol-driven processes of care are considered "best practices" and have become the standard of modern critical care.

Measuring quality in the ICU

Lengths of stay, mortality, risk-adjusted mortality, complication rates and days of mechanical ventilation have long been traditional measures of patient outcomes in the ICU. Two recent papers address the question of ICU quality measurement by measuring compliance with protocols known to reduce ICU complications and improve survival. First, de Vos et al. identify 11 quality indicators using an exhaustive literature review and expert opinion. These include such structural characteristics as availability of intensivists, patient-to-nurse ratio, and strategies to prevent medication errors. They also identified other measures felt to be indicative of high quality process of critical care including maximum and minimum glucose measurements and the percent of days with all ICU beds occupied. They also measured outcome using number of unplanned extubations and the incidence of decubitus ulceration.(71) Then, DuBose and colleagues, conducted a prospective before-after trial of rounding in the ICU with a checklist of best-practice protocols and documenting their implementation. Using this checklist, they realized an improvement in ventilator-associated pneumonia prevention practices, peptic ulcer and deep venous thrombosis prophylaxis compliance. They also observed a decrease in central line days and duration of mechanical ventilation. They concluded that the practice of rounding with a checklist resulted in a sustainable improvement in patient outcomes.(72)

Your group opts to expand and take on all emergency general surgery (EGS) care.

- Will this action impact negatively on the care of trauma patients in the system?
- Will the need to also care for injured patients impact negatively on the care of the EGS patients? Does the presence of an EGS service improve patient outcome?
- How should resident hours/responsibilities be handled to maximize educational opportunities and be compliant with ACGME regulations?
- What kinds of operative cases will this responsibility likely generate?

EMERGENCY GENERAL SURGERY AND THE TRAUMA SURGEON

As trauma surgery has evolved over the recent two decades, its practitioners have realized that they face a crisis. Several issues have been identified that are the driving force for the changes taking place, the results of which are manifested as fewer surgeons pursuing careers in trauma. Leaders in contemporary American trauma surgery have postulated that external forces including perception among medical students and current residents regarding the suitability of a trauma career, diminishing reimbursement for trauma care and a general trend in American medicine toward increasing specialization have played a role in decreasing the ranks on active trauma surgeons. Additionally, trends from within the field of trauma surgery have contributed to this phenomenon. Specifically, nonoperative management of solid organ injury has decreased the operative experience of general surgeons caring for injured patients. In response to this, Jukovich et al. writing on behalf of the AAST in 2005, articulated the above noted issues and proposed a new specialty combining trauma and elective and emergency general surgery. This is known as "Acute Care Surgeon: Trauma, Critical Care and Emergency General Surgery."(73)

The practice of emergency general surgical and trauma consults and cases being done by the same general surgeon or team is not a new concept. Many centers had practiced in this model for some time before the publication of the AAST article. Spain and colleagues detailed their experience of the trauma/EGS model at the University of Louisville Hospital. They observed that nontrauma patients accounted for 34% of all the trauma service admissions over a 6-year period. They concluded that their model allowed for the maintenance of operative skills and buffered the impact of variations in trauma volume.(74) Similarly, Pryor and coworkers compared two 15-month periods before and after the addition of an emergency general surgery practice to the trauma service at the University of Pennsylvania in Philadelphia. Finding no significant differences in the mortality rates of the two groups, they concluded that the addition of emergency surgery responsibilities did not adversely impact the care of injured patients. (75) Scherer and Battistella reviewed the experience of a Level I trauma center and found that the addition of the EGS duties, the number of operative cases were nearly triple that of a trauma-only model.(76) Kim and coworkers queried the trauma registry and perioperative database of an urban Level I trauma center to evaluate changes in operative caseload over a 3-year period as the institution integrated EGS into the duties of the trauma services. They found that operations for trauma decreased while operations for EGS patients increased. They also conducted an anonymous survey that revealed improved satisfaction among trauma surgeons in response to the implementation of the combined trauma/EGS services.(77) Austin and colleagues performed a database review at another Level I institution as their department was restructured to include an EGS service. They found case volumes increased for both the trauma surgeon and the elective general surgery staff. This restructuring also generated increased use of ICU and operating room resources.(78) Kaplan and colleagues analyzed a prospective database of consultations, operations, and procedures developed after the launch of the EGS/Trauma model. Their cost-benefit analysis revealed that increase in operative volume and billings came at the cost of individual time and time available for recruiting other staff.(79)

The addition of EGS responsibilities to the trauma services affords improved outcomes of EGS patients when cared for by the trauma service. Earley et al. found over a 3-year period that among patients with acute appendicitis, the acute care surgical model was associated with decreased time to operation, rupture rate, complication rate and hospital length of stay compared to the traditional home-call model.(80)

RESIDENT EDUCATION, ACGME REGULATIONS AND ACUTE CARE SURGERY

The ACGME mandated that beginning on July 1, 2003, all accredited residency programs in the United States limit the work hours for all residents. This mandate had a profound impact throughout departments of surgery across the country. The specific effect on the trauma services was no different. Salim and coworkers conducted a retrospective cohort study at an academic Level I trauma center. They compared trauma patients admitted during 24-month periods before and after implementation of the ACGME regulations. They found no significant differences in overall mortality during the two periods. However, they did observe a significant increase in complications and concluded this increase could be attributable, in part, to the ACGME edict. (81) Patient safety concerns, manifest as increased intensive care unit readmissions, were addressed by Frankel and coworkers with a structured transfer protocol. They realized a decrease in the readmission rate to levels similar to pre-ACGME regulation levels.(82) A number of strategies have been employed to conform to the ACGME mandate. In addition to using midlevel providers to supplement housestaff shortages, the Association of Program Directors of Surgery survey revealed "night float" team configuration and the use of housestaff from residencies other than general surgery as ways of complying with the ACGME restrictions.(55)

The general surgery operative caseload of the acute care surgeon has been described for a variety of geographic locations, though all from Level I trauma centers. Overall, the operative experience was varied; yet tended to focus on abdominal operations. There are common trends despite the variation in settings. For example, appendectomies were the most common operation in all but Austin's report from Vanderbilt University in Nashville, TN.(78) Operative management of soft tissue infections, including incision and drainage procedures also figured prominently in reports from Garland and colleagues (83) and Maa et al. (84) in California, and Pryor and coworkers in Philadelphia.(75) Interestingly, Maa's paper reports a 7% rate of complex liver, spleen and pancreas cases performed by the group of three surgical hospitalists at the University of California-San Francisco Medical Center. Other operations that were common among the reports included cholecystectomy, hernia repairs, and various intestinal resections.

As we have seen from the preceding chapter, the evolving field of trauma/critical care surgery has created a new entity whose job description now also includes emergency general surgeon. This acute care surgeon or surgical hospitalist will provide care to surgical patients in the settings of trauma or other emergent surgical presentation and provide ongoing care in the surgical intensive care unit.

Preparation for this career would consist of a 24-month acute care fellowship following completion of an ACGME accredited general surgery residency. Jurkovich et al. outlined the specific curriculum in the 2005 AAST report. This fellowship curriculum includes 9 months of surgical critical care then 15 months of emergency and elective surgical rotations including vascular, hepatobiliary, and thoracic experiences. Additionally, it has been proposed that the training experience also involve rotations on neurosurgical and orthopedic surgical services so that, "…the new trauma surgeon specialist could also perform selected and limited … procedures, with national and local support from those fellow surgical specialists."(73)

Finally, we have seen the contributions of midlevel providers to critical care and trauma teams in terms of improved patient outcomes. There is little doubt that these nurse practitioners and physician assistants will continue to be as in demand as the acute care surgeons themselves as the new frontier of acute care surgery continues to evolve and unfold (Table 1).

Table 1 Grade of Evidence for Selected References.

Ref. No.	Author, Journal, Year	Grade of Evidence
Does ACS verification improve outcomes in trauma centers?		Weak recommendation in favor
2.	Norwood, Journal of Trauma, 1995	2B
3.	Ehrlich, Journal of Trauma, 2002	2B
4.	Piontek, Journal of Trauma, 2003	2B
5.	MacKenzie, New England Journal of Medicine, 2006	2A
6.	Scarborough, Archives of Surgery, 2008	2B
7.	Demetriades, Journal of the American College of Surgeons, 2006	2A
Does the presence of an in-house trauma surgeon improve patient outcomes?		Weak recommendation in favor
8.	Esposito, Journal of Trauma, 2006	2C
9.	Kim, Journal of Trauma, 2007	2C
10.	Rogers, Journal of Trauma, 1993	2B
11.	Durham, American Journal of Surgery, 2005	2B
12.	Demarest, Journal of Trauma, 1999	2B
13.	Luchette, Journal of Trauma, 1997	2B
14.	Fakhry, Journal of Trauma, 2000	2C
Does the presence of midlevel providers contribute to patient outcomes?		Weak recommendation in favor
16.	Miller, Journal of Trauma, 1998	2B

17.	Haan, Journal of Trauma, 2007	2C
18.	Oswanski, American Surgeon, 2004	2C
19.	Christmas, Journal of Trauma, 2005	2B
20.	Nyberg, Journal of Trauma, 2007	2C
21.	Kaups, Journal of Trauma, 1998	2C
Can patient outcomes be objectively measured?		Strong recommendation in favor
26.	Hemmila, Surgery, 2007	1C
32.	Aitken, Injury, 2007	1C
34.	Soberg, Journal of Trauma, 2007	1C
Does the availability of an intensivist 24/7 improve outcomes among critically ill patients?		Weak recommendation in favor
37.	Pollack, Critical Care Medicine, 1988	2B
38.	Reynolds, JAMA, 1988	2B
39.	Brown, Chest, 1989	2B
41.	Pronovost, JAMA, 1999	2B
42.	Ghorra, Annals of Surgery, 1999	2B
43.	Dimick, Critical Care Medicine, 2001	2B
44.	Pronovost, JAMA, 2002	2B
45.	Kahn, Quality and Safety in Health Care, 2007	2A
46.	Levy, Annals of Internal Medicine, 2008	1B*
47.	Gajic, Critical Care Medicine, 2008	2A
48.	Breslow, Critical Care Medicine, 2004	2B

*Evidence against intensivist staffing model

Is there an ideal physician-to-bed ratio for ICUs?		Weak recommendation in favor
50.	Dara, Chest, 2005	2B
Does a "closed ICU" model improve outcomes in critical care?		Weak recommendation in favor

51.	Multz, American Journal of Respiratory and Critical Care Medicine, 1999	2B
52.	Carson, JAMA, 1996	2A
53.	Treggari, American Journal of Respiratory and Critical Care Medicine, 2007	2B
54.	Nathens, Annals of Surgery, 2006	2B
Do midlevel providers on the critical care team contribute to improved patient outcomes?		Weak recommendation in favor
55.	Gordon, American Surgeon, 2006	2C
56.	Dubaybo, Chest, 1991	2C
57.	Hoffman, American Journal of Critical Care, 2003	2B
58.	Hoffman, American Journal of Critical Care, 2004	2C
59.	Hoffman, American Journal of Critical Care, 2005	2B
60.	Hoffman, Respiratory Care, 2006	2B
Do a multidisciplinary critical care team and protocol-directed processes of care improve outcomes for critically ill patients?		Weak recommendation in favor
61.	Leape, JAMA, 1999	2B
62.	Montazeri, Critical Care Medicine, 1994	2C
63.	Kopp, American Journal of Health System Pharmacists, 2007	2C
64.	Braga, Journal of the American Dietetic Association, 2006	2C
65.	Kollef, Critical Care Medicine, 1997	1B
66.	Brook, Critical Care Medicine, 1999	1B
67.	Girard, Lancet, 2008	1A
68.	Van den Berghe, New England Journal of Medicine, 2001	1A
69.	Taylor, Journal of the American College of Surgeons, 2006	2B
70.	Barr, Chest, 2004	2B
Can quality be measured objectively in the ICU?		Weak recommendation in favor
71.	de Vos, Journal of Critical Care, 2007	2C
72.	DuBose, Journal of Trauma, 2008	2B

Can trauma surgeons care for EGS patients and maintain quality outcomes for both populations of patients?		Weak recommendation in favor
74.	Spain, Journal of Trauma, 2000	2C
75.	Pryor, Journal of Trauma, 2004	2B
76.	Scherer, Journal of Trauma, 2004	2B
77.	Kim, Journal of the American College of Surgeons, 2004	2C
78.	Austin, Journal of Trauma, 2005	2B
79.	Kaplan, Journal of Trauma, 2005	2B
80.	Earley, Annals of Surgery, 2006	2B
81.	Salim, Archives of Surgery, 2007	2B
82.	Frankel, Journal of Trauma, 2006	2B
83.	Garland, American Journal of Surgery, 2007	2C
84.	Maa, Journal of the American College of Surgeons, 2007	2C

Scheme for grade of evidence adapted from Guyatt et al. (85)

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Trauma, Critical Care and Surgical Emergencies

A Case and Evidence-Based Textbook

About the book

This book provides a comprehensive and contemporary discussion about the three key areas of acute care surgery; trauma, surgical critical care, and surgical emergencies. The 65 chapters, written by prominent surgeons in the field, are arranged by organ, anatomical site and injury type, and each includes a case study with evidence-based analysis of diagnosis, management, and outcomes. Unless stated otherwise, the authors used the GRADE evidence classification system established by the American College of Chest Physicians.

Trauma, Critical Care and Surgical Emergencies is essential reading for all surgeons, fellows, residents and students, especially those working in trauma, emergency and critical care environments.

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With an introduction on Evidence Based Medicine by Timothy C Fabian MD, Wilson Alumni Professor of Surgery and Chairman of the Department of Surgery, University of Tennessee Health Science Center, Memphis, Tennessee, USA.